



FACULTY OF TECHNOLOGY

# **Robotization and Digitalisation in the Construction Industry**

Sagar Kumar

Supervisor(s): Dr Janne Härkönen, Dr Erno Mustonen

INDUSTRIAL ENGINEERING AND MANAGEMENT

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# ABSTRACT FOR THESIS

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| <p>Abstract</p> <p>Industry 4.0 has emerged as a famous concept in the last few years to describe the significance of digitisation and robotization in the smart manufacturing environment. The advancements in robotics, digital software, and smart technologies have allowed a new wave in the construction industry. The construction industry is the major economic pillar and provides a significant impact on the overall GDP of the country. Despite the predominant pillar, it is considered as the poor innovator and late adopter of new technologies, which ends up with delays and cost overruns in their construction projects. Considering this aspect, the research emphasises the importance of adopting the latest technologies in the construction industry in order to enhance the productivity and efficiency of various processes. This study seeks to examine existing robotization and digitalisation practices in the leading construction companies and intends to provide the required improvement ideas in this research domain.</p> <p>The empirical results revealed that the majority of the case companies lack basis to implement the latest technologies in their construction activities. They believe that effective use of the available technologies is an asset, but it is a long process to be achieved. Thus, the thesis is concluded by providing the critical information regarding the adoption of latest technologies and proposes a framework that can help to enhance the robotization and digitisation practices to improve the performance of the construction activities. The mentioned framework mainly focusses on elements that this research found as a potential need for companies to implement. This framework has a future scope for validation and also key elements of the framework can be utilised for further research.</p> |                                 |  |                               |
| <p>Additional Information</p> <p>Keywords: Industry 4.0, Digitalisation, Robotization, Construction Industry, Enabling technologies</p>  |                                 |  |                               |

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## LIST OF ABBREVIATIONS

|      |                                      |
|------|--------------------------------------|
| 3D   | Three Dimensional                    |
| 5G   | Fifth Generation Network             |
| AR   | Augmented Reality                    |
| BIM  | Building Information Model           |
| CDO  | Chief Development Officer            |
| CR   | Collaborative Robot                  |
| DDK  | Digital Design Knowledge             |
| DQ   | Data Quality                         |
| DT   | Digital Twin                         |
| GDP  | Gross Domestic Product               |
| I4.0 | The Fourth Industrial Revolution     |
| IFR  | International Federation of Robotics |
| IoT  | Internet of Things                   |
| IQ   | Information Quality                  |
| PDM  | Product Data Management              |
| PLM  | Product Lifecycle Management         |
| R&D  | Research and Development             |
| RFID | Radio-frequency identification       |
| ROI  | Return of Investment                 |
| VP   | Vice President                       |
| VR   | Virtual Reality                      |

# 1 INTRODUCTION

## 1.1 Background

The construction industry is a massive predominant industry (Kamaruddin *et al.* 2016) and can be one of the domestic economy pillars (Egan 1998, Thompson *et al.* 2017) that contributes to about 6-10% of the GDP in the developed countries (Balaguer & Abderrahim 2008, Wang 2019, European Commission) and about 25% in developing countries (Kim *et al.* 2015). However, on the other end the construction industry is also said to have the lowest capital investment as well as low capital intensity compared to other industries due to reasons like inappropriate working conditions, may these be related to sub-par human conditions or technological inadequacies (Bock 2015). Many references can be found to support the standpoint on the construction industry of being a poor innovator and a late adopter of new technologies (Bakir & Balchi 2018, Abbot *et al.* 2006). Delays and cost overruns are common phenomena in construction engineering projects (Thompson *et al.* 2017, Sambasivan & Soon 2007, Toor & Ogunlana 2008). Several studies have contributed to this research by identifying some causes for delays such as lack of quality information (Frimpong *et al.* 2003), design complexity, delays in design information (Assaf & Al-Hejji 2006), and changes in scope (Sambasivan & Soon 2007). As per Bock (2015), achieving efficient process efficiency in the construction industry can be done through the use of advanced technologies that have been used in recent years. Hence, digitalisation and robotization are two relevant subjects when studying the utilisation of advanced technologies in construction industry.

Due to the recent technological developments such as advanced robotization together with the enabling digital technologies (e.g. building information modelling, digital twin, etc.) are providing significant scope for enhancing the overall performance and efficiency of the smart construction sector and bring economic benefits as well (Vilutiene *et al.* 2019, Tao *et al.* (2017)). However, the state-of-the-art lacks much deeper analysis and validation of these technological trends from the perspective of the large-scale construction organisations. Moreover, the major research gap is to analyse why construction companies do not take benefit from these technological evolutions. Thus, it is important to study what is the current opinion/status of these companies regarding the

frequent adoption of these technologies. In addition, another key literature gap is the lack of a basic framework towards achieving digitalisation and robotization in construction companies. Hence this thesis aims to fill this gap by validating it with the empirical research and further work on approaching towards an efficient framework.

## 1.2 Research problem and objectives

This study aims to explore and identify the practices and techniques for digitalisation and robotization, which have the ability to enhance productivity in the construction industry like infrastructure, prefabrication activities and overall process life cycle etc. The fourth industrial revolution (I4.0) concept has promised significant opportunities for providing various technological solutions such as digitalisation and robotization of the industrial processes using enabling technologies and data management methods which are highly crucial for the construction sector. It will allow the construction companies to reduce the production costs and time, perform tedious and dangerous tasks with the help of digital collaboration.

Considering the aim of this study, the objective of this study can be formulated to answer the following research questions to achieve the goals of this thesis (RQs):

### ***RQ1: Why are robotization and digitalisation essential in the construction industry?***

The purpose of the RQ1 is to explore and analyse the importance and the role of robotization and digitalisation in the construction sector by evaluating the current literature review. Further, the research goes to investigate more specifically, how various enabling technologies such as building information modelling (BIM), digital twin, augmented reality/virtual reality, etc. can play a significant role in the construction domain.

### ***RQ2: What is the current state of robotization and digitalisation in the studied construction companies?***

This question will be answered by interviewing well-known construction companies in Finland. It will analyse, what kind of digital technologies and robotization practices companies currently have and at what extend, do these companies have understanding about the importance of digitalisation and robotization technologies.



***RQ3: How can robotization and digitisation be improved in the construction companies?***

Results obtained from the literature (RQ1) and empirical research (RQ2) will provide information about practical applicability of these technologies, which will help to construct a framework that will give some beneficial aspect in order to adopt technologies.

### 1.3 Research process

The research process for this study is comprised of three integrated phases, the literature review, empirical research and the results and conclusion, which can be seen in Figure 1. The literature review is conducted to develop the theoretical foundation of robotization in the construction industry. After that, it is focused on the prefabrication practices in the construction industry that brings benefits in the assembly processes. Later it is addressing the integration of digital design knowledge (DDK) and digital twin (DT) with augmented reality (AR) and data management method on how digitalisation can play a role with robotization of the construction process. Finally, the result of the literature review part has been synthesised, and potential outcomes can be utilised towards the foundation of empirical research. Moreover, empirical research is organised by applying a qualitative research methodology. In this study, the detailed questionnaires are created from the theoretical framework to conduct a semi-structured interview from the personnel of the four case companies. It allows to validate the theoretical findings and obtain the cross-comparison and enables to analyse the results. Further, both the literature review and empirical research provides a base to create a framework in the results and evaluation section to answer research question 3.

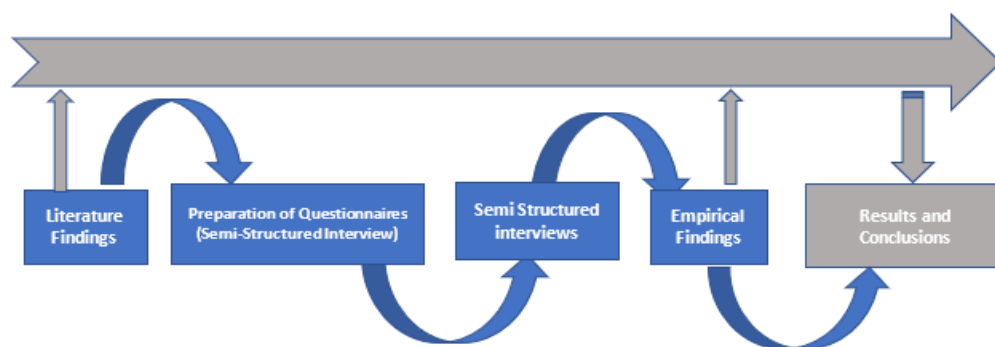


Figure 1. The research processes

## 2 THEORETICAL FOUNDATION

### 2.1 Industry 4.0 in construction

Today, advancements in robotics, digital software, and smart technologies have allowed a new wave of automation in the construction industry (Higgins 2019, Kamaruddin *et al.* 2016). Various authors have defined Industry 4.0 in general, however, the best-researched definition was “Industry 4.0 is the industrial internet, smart factory or advanced manufacturing system that brings benefits to the production, machines, processes or equipment which allows the transformation of the complete value chain of shop-floor with the help of information and communication technologies in the manufacturing ecosystem” (Barbosa & Aroca 2017, Oesterreich & Teuteberg 2016, Rao & Prasad 2018). Industry 4.0 aims to connect the physical world with digital technologies to get a high-level of operational productivity and efficiency in the industrial processes (Wagner *et al.* 2017, Weyer *et al.* 2015, Peruzzini *et al.* 2017).

As per Alaloul *et al.* (2018), Ortiz *et al.* (2009), and Maskuriy *et al.* (2019), Industry 4.0 is still in the beginning stage and construction industry is still far behind to adopt enabling technologies and digital automation (Alaloul *et al.* 2018, Ortiz *et al.* 2009, Maskuriy *et al.* 2019). However, it has the ability to reforms the traditional industrial approaches by adding computerised and digitalised mechanisms along with recent technologies such as the internet of things (IoT), fifth-generation (5G) mobile networks, cloud computing (CC), virtual reality/augmented reality, building information modelling (BIM), big data and, digital manufacturing and advanced materials (Rao & Prasad 2018, Lu 2017). Osunsanmi *et al.* (2018) state that even after considering the advantages of the technologies provided by Industry 4.0, the construction industry has not been able to utilise all the technologies as compared to the manufacturing sector (Osunsanmi *et al.* 2018). Two of the main challenges in the implementation of these technologies in the construction industry were a high initial investment (Shrestha & Kumaraswamy 2011) and low investment in the research and development (R&D) domain towards innovation inclined towards construction (Oesterreich & Teuteberg 2016). Technologies like additive manufacturing and big data analytics are still in the emerging stage, which can

provide a huge impact on the business in the construction industry (Roland Berger GmbH. 2016).

Further, Figure 2 shows the framework that puts a light in recognising Industry 4.0 as the creation of the smart construction site, simulation and virtualization that will, in turn, lead to improved construction project performance (Osunsanmi *et al.* 2018). The innovation to construction automation is still in the immature stage (Niu *et al.* 2015) and still needs more R&D from the technical aspects point of view on the available technologies such as BIM, cloud computing, mobile computing, and modularization (Oesterreich & Teuteberg 2016).

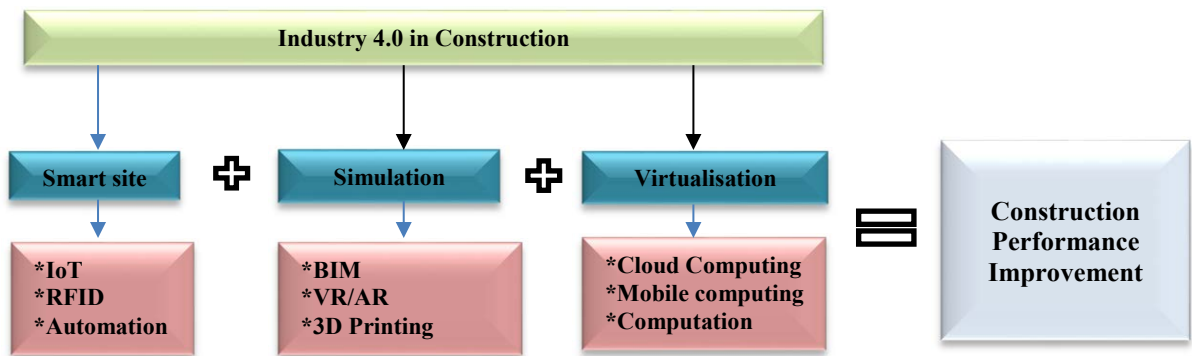


Figure 2: Conceptual roadmap for construction performance enhancement (Modified from Mahamood & Akinlabi.2017, Oesterreich & Teuteberg 2016, Osunsanmi *et al.* 2018)

## 2.2 Robotization in construction

### 2.2.1 Introduction to robotization

Innovation is considered as a key component to developing the competitive nature and performance of any industrial sector. Especially, in the construction and building industry, continues development of systems and services are key elements which give new directions to the future of the industry (Bachas 2001). Currently, traditional methods and practices used in the construction industry are facing challenges to fulfil the increase in the demand for productivity and improving system effectiveness. Therefore, innovative directions would be needed for the traditional systems by combining existing technologies with the advance robotic and automation technologies (Bakir & Balchi 2018, Gambao *et al.* 2000).

Institute of America defines robot as a “reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialised devices, through variable programmed motions for the performance of a variety of tasks” (Barfield et al. 1995, pp. 473-513). Robotics and automation systems have been developed from a long period of time and to be utilised in various industrial activities. Further research classifies the robotic and automation utilisation in the construction industry in two sectors that are civil infrastructure and house building sectors (Vähä *et al.* 2013). Civil infrastructure robots are mainly used for the automation of road, tunnel and bridge construction, earthwork, etc. And robots in the house-building sector include building skeleton erection and assembly, concrete compaction, interior building finishing, bricklayer masonry, column welding, modular industrialized building’s construction etc. (Balaguer & Abderrahim 2008). Hence when it comes to the beneficial point of view, there are various benefits of utilising robot in the construction industry, but the potential benefits are the reduction in time and cost, coverage the shortage of labour, substantial reduction of project lead time and improved overall operational efficiency (Bakir & Balchi 2018, Gerling & Von 2016).

As per Steidel (2019), robots will be used in future to aid human workers while performing physical tasks. Typically, in the construction assembly, a collaboration of human robots performs repeated accumulated tasks by utilising necessary resources to achieve the common objective (Steidel 2019). Even though digital fabrication and modular parts are mostly created in dedicated factories, which are later on transported to the building site for the final assembly, there would be a time consumption challenge faced due to the low level of robotics capabilities on construction site, especially the time consumed is increased during the assembly process (Kim *et al.* 2015). Thus, advanced robots would be required to reduce cost, time and enhance the efficiency of the project, especially during the construction process (De Soto *et al.* 2018). Moreover, the integrated digital design and prefabrication process may be achieved through the utilising of digital collaborative robots. These types of robots will bring more construction flexibility and controllability during activities. As construction tasks are complex in nature, but through the Human-robot collaboration, it can be accomplished with higher productivity (Vasey *et al.* 2016).

According to the researcher from the University of West of England (UWE), robotics technologies have potential to provide significant benefits to the construction industry,

but due to the complicated industrial framework leads towards the poor adoption. They have suggested critical challenges which are main factors for limiting the adoption of robotics, like, weak business case factors, technical and work culture factor, client and contractor side economic factors. These major disruptions may be considered to ensure successful adoption. (Delgado *et al.* 2019)

### 2.2.2 Potential robots utilised

#### *Collaborative robots*

According to Vasey *et al.* (2016) and Afsari (2018), collaborative robots (CR) are considered as a robot which can work closely with humans while sharing the same workspace. It is interacting with humans and enables human workers to perform tasks closely with machines to achieve common work objectives (Afsari 2018, Vasey *et al.* 2016). Further, various authors have explained that CR is a smart and skill-based of both hardware and software machine which connects human and robots together at the collaborative workplace to perform numerous functions like, manipulates various object, support repetitive and critical tasks with human safety assurance (Ryymin *et al.* 2019, Schou *et al.* 2018, Afsari *et al.* 2018). The famous collaborative robot manufacturers are FANUC, KUKU, and ABB (Mathieu 2017). According to the International Organisation for Standardisation (ISO/Technical Specification 15066), the principle of human-robot collaboration may contain one or more functions to perform collaborative tasks, i.e. speed and separation monitoring, hand guiding, power and force limiting, and most important safety monitored stop function (Salmi *et al.* 2018, pp. 25, Tölli 2019). With these functions, CR can enhance its applications in the prefabricated construction activities, typically in the assembly phase (ETH Zurich 2018, Steidel 2019).

Moreover, CR allows to have a human-robot collaboration that brings numerous benefits in the prefabrication construction processes like enhances productivity, flexibility, efficiency, safety etc. (ETH Zurich 2018, Hägele *et al.* 2005, Li *et al.* 2014). In the large-scale assembly phase, material handling process is considered as a high-resource consuming task. As on the construction site, a lot of efforts are spending on material handling activities during the final assembly phase (Gambao *et al.* 2012). Thus, in this stage, utilisation of CR automation technologies reduces the physical workload of the

workers and allows to strengthen the productivity and safety at the site (Steidel 2019, Asplund & Brile 2017). Also, it reduces the risk of product damages which brings a high volume of production at low cost (Helm *et al.* 2014, Weckenborg *et al.* 2019). However, with potential benefits of CR, the adoption rate of overall automated and robotics system in the construction industry is still low (Delgado *et al.* 2019), as manufacturers are facing various challenges to fully utilise the robotics capabilities on sites (Eversmann *et al.* 2017). Like, it is still considered as a difficult task to install robotic systems in the construction activities due to the challenging environment of sites (Delgado *et al.* 2019).

As per several research authors, one of the main issues faced by the manufactures is the portability of the machine and safety of human while interacting with robotic-machine, which avoids using the high-utilisation rate of the robotic system, creates fault tolerance and cybersecurity issues. (Bier 2018, pp. 49-55, Murtua *et al.* 2017, Hentout *et al.* 2018, Schou *et al.* 2018). Programing procession plays an important role in having controlled overall operational efficiency (Schou *et al.* 2018). However, developing special equipment's which can be reduced portability issue, like dismantled features etc. and more advanced features would improve the safety of human workers. (Bier 2018, pp. 49-55, Murtua *et al.* 2017).

### *Wearable Robots*

Wearable robotic devices are becoming feasible due to the advancement in lightweight materials, sensing, and actuation technologies (Vatsal & Hoffman 2018). Wearable robots serve to replace human limb capabilities that have been lost, are used as rehabilitative tools, and can enhance and augment the human load-carrying capacity. (Choo & Park, 2017). This would lead to the drastic emergence of wearable robots in the construction industry (Li & Daniel 2018). A very good example is the exoskeleton which is able to endow the operator with more strength beyond his natural limits and allow the worker to handle heavy objects during their construction activities such as carpentry or fitting ceiling boards as they require large muscular power (Vatsal & Hoffman 2018, Choo & Park 2017).

However, there the increased complexity of the wearable robot mechanism would affect the reality of the system (Choo & Park 2017). Also, some workers are worried that the

advance use of wearable robot would replace them (Li & Daniel 2018). Further, research suggests that an integrated wearable robotic system keeps the construction workers in safer postures by imposing behavioural constraint using a passive exoskeleton (Cho *et al.* 2018). According to a global report study, around 40 companies are manufacturing exoskeletons worldwide to deploy them on their respective construction sites (Market research future 2019).

### 2.2.3 Observed trends in robotization in construction

The construction industry is one of the sectors, which is not much familiar with the R&D fields for automation and robotics community (Hampson *et al.* 2014, De Soto *et al.* 2018). However, it is an industry that contributes to high economic benefits for any country. Despite the fact that the R&D investment for the construction industry is low as compared to the other industries (Thompson *et al.* 2017). However, advancement in the enabling technologies trend allows European construction robot market to grow due to the increasing demand for construction and demolition robots in various facilities. Also, new government regulations, growth in residential and non-residential construction projects demand to adopt robotic technologies (Market research future 2019).

According to the international federation of robotics, globally shipment construction robot reach up-to the valuation of USD \$16.5 billion in 2018 with a forecasted growth of 12% by 2022, which is considered that in the construction activities, industrial robots would be highly useful for human-robot integration (IFR 2019). Further, as per Francis (2017), the next couple of years there will be an increase in the usage of robots in the prefabrication construction and, robotics and automatic technologies would be accessible and affordable to install in the prefabrication activities. (Francis 2017)

Moreover, the utilisation of collaborative robots on construction sites and construction manufacturing activities could bring various advantages for workers in different ways. It can conduct tedious tasks with a high level of flexibility, accuracy and reducing fatigue and stress for workers. (Arrunada *et al.* 2018). According to the IFR, around 14,000 units of collaborative robots were installed from more than 422,000 industrial robots in 2018, which is still a very low share of installed robots as compare to industrial robots (IFR 2019). Although the robotic market has not reached up to the maturity stage, however in

future, it will be highly demandable in the Asian, America and European regions (Markets and markets 2019). Functions, like incorporate safety and flexibility capabilities, would raise the popularity of collaborative robots in the construction industry to perform collaborative operations with human workers (Brown & Woods 2017).

## 2.3 Prefabrication in construction

Researchers say that robotics, digitalisation, smart-building components manufacturing methods and advanced technology are the key elements to drive the prefabrication industry (Bock & Linner 2015, pp.12). Experts have realised that adoption of automation and robotics technologies accelerates high growth in the prefabricated construction industry (Francis 2017, Ross *et al.* 2006, Kutuba, T. (2017). These days, many start-ups are investing in the robotics and automation technologies to make their production smarter for constructing prefabricated building parts, like kattera, a technology-driven offsite construction company (Kattera, Francis 2017). Robotic setup in the large-scale prefabrication processes brings significant benefits in drilling, cutting and additive robotics operations. Such type of digital workflow in the assembly can improve productivity with higher accuracy as well as low noise emission and fast construction. (Eversmann *et al.* 2017, Zukunft-Bau 2019). Researchers from ETH Zurich, have utilized the robots to develop a new method for the large-scale prefabrication in architectural timber project. They have assembled fabricated timber parts with the collaboration of robotic machines and human (ETH Zurich 2018).

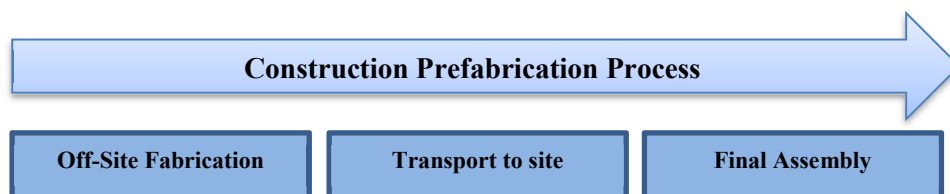


Figure 3 : Construction prefabrication process (Azman *et al.* 2012, Ross *et al.* 2006)

Paudel *et al.* (2016), has suggested that any building or its parts, segregated into various sections, components or sub-products that can be built into the industrial environment and integrated onsite, falls in the prefabrication building category (Paudel *et al.* 2016). This



means finished building elements have been prior manufactured in the offsite places and then transported to the required location to be fitted or assembled onsite as shown in above Figure 3. (Azman *et al.* 2012, Ross *et al.* 2006). Nowadays, the construction industry is facing numerous challenges that create tremendous pressure to change and innovate the ways in which manufacturers are operating constructing projects (Tam *et al.* 2007). Hence prefabricated parts are considered as a modern method of construction which allows to minimize cost, reduce a large amount of waste, helps in completing tasks on time, reduces labour cost and, enhanced efficiencies and intended quality of the overall project (Zhang *et al.* 2014). Research authors like Alonso-Zandari and Hashemi (2016), Kutuba (2017), and Wu (2017), have conducted extensive research on the barriers and challenges in the pre-fabrication process, as shown in Table 1.

Table 1: Benefits and challenges in the prefabrication process (Modified from Alonso-Zandari & Hashemi 2016, Kutuba 2017 and Wu 2017).

| Potential benefits   | Barriers   |
|--|--|
| Time and cost savings  | Engineering technical issues                               |
| Reduces construction waste   | Inflexibility in the change in design                      |
| Enhanced product quality   | Need for expertise   |
| Higher productivity levels   | Site space requirements for pre-fabrication large assembly |
| Green construction objectives like, Reduction in noise and dust pollution etc. | Time and cost required for initial implementation          |

According to Wu (2017) and Smith (2010), the construction prefabrication level can be illustrated into three categories: components, panels and modules shown in Figure 4. Components, such as timber, concrete, steel or anything which can be utilised for different materials in the factory. Further at the panel level, prefabricated roofs, partition walls are considered as panelised systems and are completely assembled on site from a single piece to the big piece, like prefabricated bathrooms, rooms are falling into the modular level. (Wu 2017 & Smith 2010).

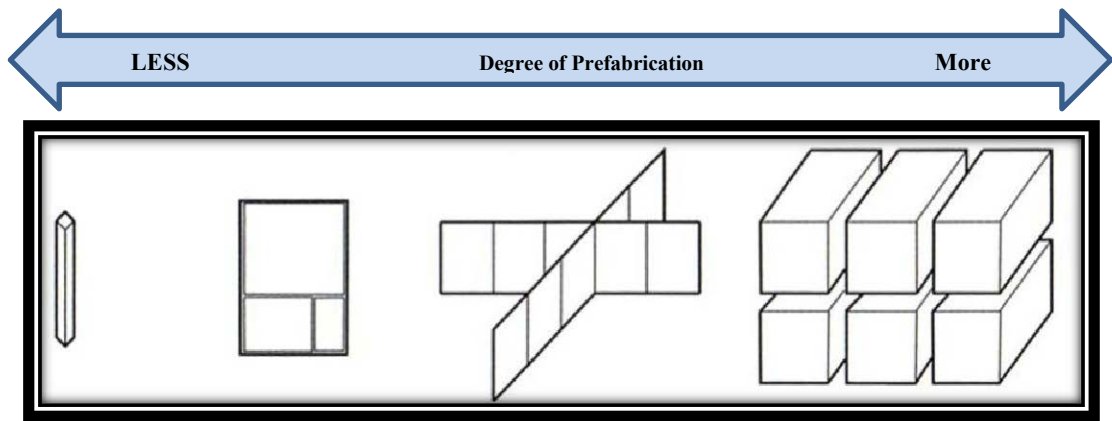


Figure 4: Degree of prefabrication (Modified from Smith, 2010)

Moreover, with increasing population demands for faster construction, shortage of skilled labour, rise in labour costs, environmentally friendly and safety issues and making construction industry greener are some critical challenges, which leads to adopting new approaches to reform traditional industry (Dainty *et al.* 2005, Singhai 2015). Hence, prefabrication is considered as one of the solutions which can assist to accomplish construction project on time with reasonable cost, safer and ecologically friendly manner. As per extensive research conducted by Paudel *et al.* (2016), it is shown that from the past two decades, the utilization of prefabrication parts has increased up to 86%. (Paudel *et al.* 2016). Smith (2009), has explained that prefabrication could be a construction strategy for in-housing production that would be harnessed to fulfil the desires and needs of the global diverse societies (Smith 2009). According to Fortune Business Insights (2019), the future of prefabrication construction looks bright. As the global market for prefabricated construction will grow up to \$107.21 billion in 2026 (Fortune Business Insights 2019). These days, circular economy or waste management is also considered as a critical issue in the construction industry, and prefabrication techniques can bring an effective solution to avoid huge waste on the offsite activities (Tam *et al.* 2007, Wu 2017). Thus, construction prefabricated through modular methods and utilisation of robotics and digital technologies will bring the construction industry to the next leap.

## 2.4 Data management in construction

Data quality management has, over the years, received increasing attention in the field of information systems (IS) (Madnick *et al.* 2009). Due to the high costs of poor data quality

(DQ) and information quality (IQ) (Ramaswamy 2006), it is important for organizations to be able to assess, manage, and maintain a sufficient level of DQ/IQ in data sources and data deliverables (i.e. drawings and other documentation). Research on DQ/IQ has been performed in a variety of contexts such as data warehousing, health care, and retailing. Researchers agree that DQ/IQ assessment is context-dependent (Strong *et al.* 1997), and several assessment frameworks and tools have been developed to fit these various contexts (Batini *et al.* 2009). Although construction engineering is a field suffering from poor DQ/IQ, unfortunately, existing frameworks and tools cannot be used for sufficient assessment since they are based on assumptions that are not valid in this context (Neely *et al.* 2006). Information is an important asset in the construction business, as decisions are taken based on the quality information available. Information is generally categorized as structured data and unstructured data (Caldas *et al.* 2005).

Considering the output of the construction sector as a final product, it can imply product data management in the construction industry which can provide a clear data system for the construction business process. According to the Silvola *et al.* (2011) and Stark (2015), Product data basically describes the product in the digital form, and it can be generated throughout the product lifecycle, starting from the development and retirement stages. Product data paradigm is the collaboration of product master data, business processes related product data and data created from the Information technology systems used in other business processes (Silvola *et al.* 2011, Stark 2015). Product data management (PDM) systems are mainly used to manage all product-related data and also product master data (Berson & Dubov 2007). The essential characteristics of the product can be achieved through the core of the product data, which is considered as a master data. Product master data can be attained mainly from the initial development phase of the product and which can be utilized and imported during the product lifecycle. (Silvola *et al.* 2019, Kroppsu-Vehkapera 2012).

Further, various authors have explained that the primary aim of the product data management systems is to secure relevant and accurate product data for the data stakeholders. It is a hub of the information system where overall product data is stored from processes for the management workflow and the information and product structure. (Terzi *et al.* 2010, Silvola *et al.* 2011, Kroppsu-Vehkapera *et al.* 2009). According to

Silvola *et al.* (2011), the information systems in product data management systems usually include various design systems like computer-aided design CAD, customer relationship management (CRM) and enterprise resource planning (ERP) and a system to store the product master data (Silvola *et al.* 2011). The following Figure 5 shows an example of the construction industry related to master data, the business process related stakeholders and product data.

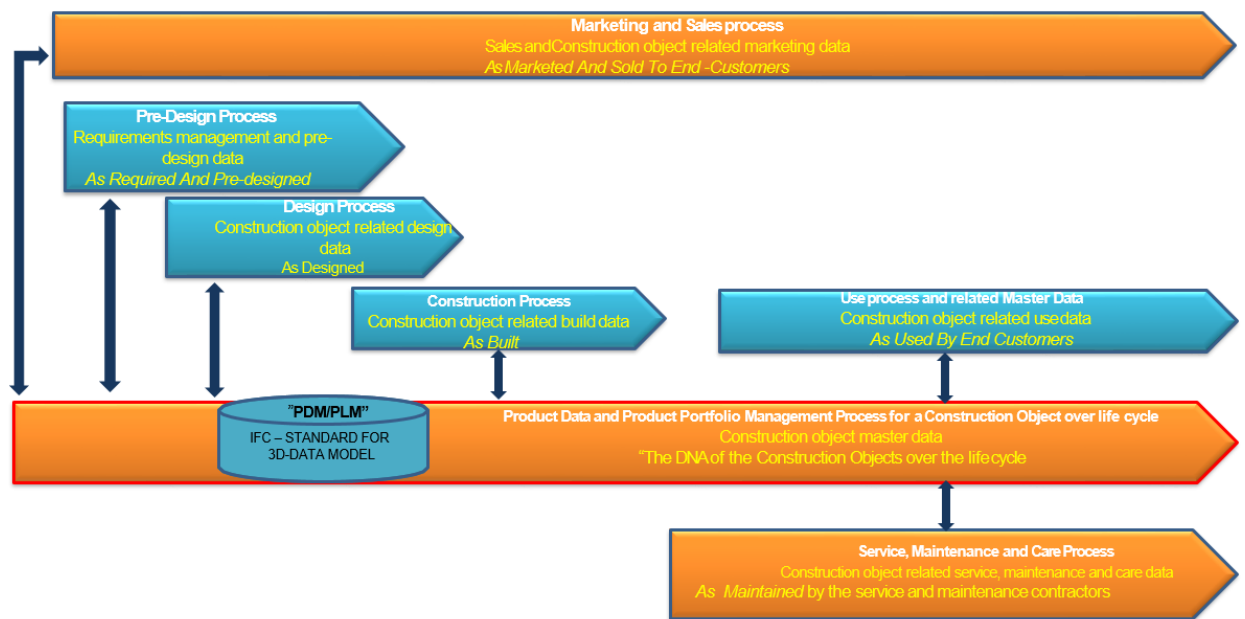


Figure 5: The construction object-related master data and the business process related stakeholders and product data (Modified from Harkonen *et al.* 2019)

However, there are various challenges in product data management in general like, data management practices, causing data quality problems which are very common in today's companies (Lee *et al.* 2013, Knolmayer & Rothlin 2006), integrating and unifying the data into the one system and providing an explicit definition for the data (Sivola *et al.* 2011). Silvola *et al.* (2019) suggested few preconditions for the one master data to provide better utilisation of data management which can also be utilised in the construction industry, can be seen in Table 2.

Table 2: Pre-conditions for master data (Modified from Silvola *et al.* 2011)

| Preconditions for master data |   |
|-------------------------------|---|
| Data Model                    | The standard definition of data model throughout the organization |
| Data ownership                | Data ownership well defined                                       |
| Data quality                  | Ensure prior data quality surveillance                            |
| Culture                       | Data-driven company culture                                       |
| Roles and responsibilities    | Explicitly defined roles and responsibilities                     |
| Organisational structure      | Hierarchy of the organization to support the data process         |
| Process                       | Clear definition of the processes                                 |
| Managerial support            | Support systems from the top-level management                     |
| Information systems           | Unified data model  |

## 2.5 Digitalisation in construction

### 2.5.1 Digital design knowledge (Building Information Model, BIM)

Over the past decade, the construction industry has seen a drastic improvement in the use of digital knowledge (Mostafa & Leite 2018). Digital design knowledge plays an important role in the construction industry. The best example of digital design knowledge currently trending in the construction industry is BIM as per various research is done in the past and presently. This chapter focusses more on BIM and gives more insights on the current trends, process and evaluation tools to study the maturity of BIM in general.

#### *Defining BIM*

Building information model (BIM) is considered as a complex technology (Kaner *et al.* 2008) and is revolutionizing the construction industry by enhancing construction technologies to the next leap and makes the construction process easier and faster for everyone involved (Sun *et al.* 2017, Vilutiene *et al.* 2019, Epstein 2012). BIM is a popular buzzword commonly used by software vendors to describe the capabilities that their products offer (Eastman *et al.* 2011). Many definitions of BIM address it as a single model as the repository for the information (Isikdag *et al.* 2007, Woo 2006). According to Yan and Demian (2008), BIM is defined as most promising and powerful technology which provides robust design management's tools to the architecture, engineering and construction (AEC) industry (Yan & Demian 2008). Ghaffarianhoseini *et al.* (2017)

consider BIM as a process for creating and managing construction-related information throughout the project-lifecycle (Ghaffarianhoseini *et al.* 2017, Latiffi *et al.* 2016).

According to Miettinen and Paavola (2014) and Correa (2018), BIM can combine various technologies (like, IoT, additive manufacturing for construction etc.) and big-data analytics solutions that can enhance inter-organizational and disciplinary collaboration in the construction industry by achieving optimized productivity while developing design, construction and maintenance practices (Miettinen & Paavola 2014, Correa 2018). However, Sacks *et al.* (2005) state that “BIM is a generic term used to describe a process of generating and managing all the information related to buildings using advanced CAD technologies” (Sacks *et al.* 2005). The national institute of building sciences (NIBS) definition of BIM can be probably considered as one of the most complete or explicit definitions of BIM: “*A Building Information Model or BIM utilizes cutting edge open standard digital technology to establish a computable representation of all the physical and functional characteristics of a facility and its related project/life-cycle information, and it is intended to be a repository of shared information for the facility owner/operator to use and maintain throughout the lifecycle of a facility.*” (Goedert & Meadati, 2008, Hannon 2007).

#### *BIM in the construction industry*

In the construction industry, BIM is considered as a collaborative process (Epstein 2012, NBIMS 2007, Hannon 2007), which introduces various stakeholders and departments in the construction industry together which can be shown in Figure 6 (NBIMS 2007). Hence, real-time monitoring of ongoing project satisfies potential stakeholder (Neves *et al.* 2019, Cecconi 2017). BIM hence provides a common platform for the collaboration of all activities and processes throughout the project (Correa & Maciel 2018). This allows Improves the accuracy scheduling, designing and budgeting aspects in construction projects (Latiffi *et al.* 2015, Ganah & John 2014, Alaloul *et al.* 2018, Correa & Maciel 2018) with accurate facilitation, visualization and simulation of the construction process (Marzouk *et al.* 2018, Trani *et al.* 2016, Becerik-Gerber *et al.* 2011, Furneaux 2008).

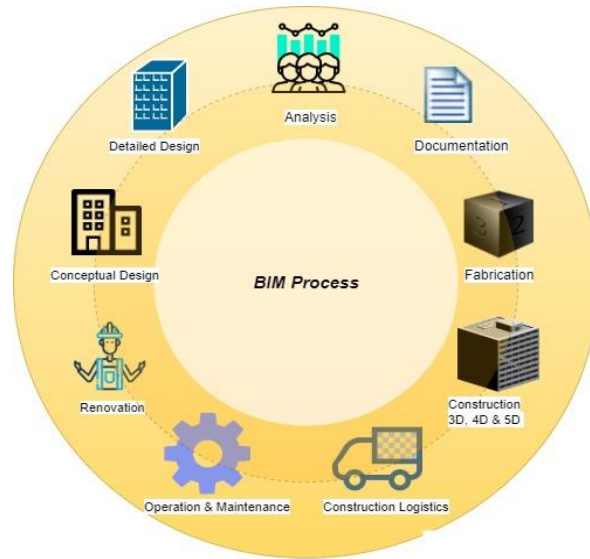


Figure 6: Amalgamation of activities related to BIM process in the construction industry (Modified from Maskuriy *et al.* 2019)

This is where BIM creates a whole new digital platform in providing an accurate and quality forecast estimate (Becerik-Gerber *et al.* 2011). It is a time-consuming process to make sudden changes to a completed building design using CAD and other design software's since there involves a process of manually maintaining numerous drawings, but at the same time, it provides a common integrated digital platform and makes the process much flexible (Vilutiene *et al.* 2019, Furneaux 2008, Li *et al.* 2017, Jiancheng 2012). BIM eliminates these pain points and automates the drawing designs and other documentation by making the changes feasible and less error-prone (Sacks 2005). The greatest advantages of BIM are the digital modelling and simulation of the project which has created in the pre-construction phase in the project to become real. Thus, BIM allows to lower the planning errors, quantifies the further cost and also provides the fast calculations, less documentations and shows replacements (Khosrowshahi & Arayici 2012, Sun *et al.* 2017)

BIM can be utilised in every phase of construction from the inception to demolition stage (Autodesk, Eastman *et al.* 2008, Azhar *et al.* 2011). Another potential benefit of BIM is that it eases the prefabrication of building components offsite, that again reduces the cost and timeline of the project (Ahn *et al.* 2016, Eastman *et al.* 2011, Latiffi *et al.* 2018, Marzouk *et al.* 2018). However, the utilising of BIM does come with several challenges.

The lack of BIM-knowledge amongst workers in the design and construction fields is an obstacle in the implementation of BIM (Gheisari *et al.* 2016, Won *et al.* 2013, Ganbat *et al.* 2018, Tulenheimo 2015, Porwal & Hewage 2013, Dong *et al.* 2014), and this makes the adoption of BIM slow (Won *et al.* 2013, Miettinen *et al.* 2014). Another major challenge is “Organizational and people-centred issues” (Porwal *et al.* 2013). In addition to this Lack of data interoperability (Maskuriy *et al.* 2019, Neves *et al.* 2019, Dong *et al.* 2014, Cao *et al.* 2015) with Lack of technological readiness level (Juan *et al.* 2017, Porwal & Hewage 2013, Dong *et al.* 2014) is considered as a major challenge in BIM these days.

According to Eastman (2008), the construction industry has been researching and developing 3D models of buildings long before the invention of computers (Eastman (2008). According to the BIM smart market report of 2009, the construction industry still proves low maturity in the BIM utilisation as there are no changes in the traditional business model to bring in new modern tools to improve the maturity of BIM (BIM smart market report 2009). "Building Information Modelling" (BIM) system is considered as “Industry 4.0” revolution of the construction industry. However, it is still in its early stages in Germany. (Balasingham 2016). The EU BIM Task Group established in 2016 was brought with the aim to provide a world-class digital construction sector that could be developed. The task of the EU BIM Task Group was “*to deliver a common European network aimed at aligning the use of Building Information Modelling in public works*” (Paul 2018). As per NBS (2019) reports, Construction professionals continue to recognise the benefits of BIM and 60% say it has brought them cost efficiencies and over half say it speeds up delivery of the project. Almost three quarters say it results in operation and maintenance savings (NBS 2019).

#### *BIM maturity level and evaluation*

In 2009, the maturity concept of BIM was separated from the capability maturity model and was introduced as the BIM maturity index (Succar 2010), with five levels of maturity: (1) Ad-hoc or low maturity (2) Defined or medium-low maturity (3) Managed or medium maturity (4) Integrated or medium-high maturity and (5) Optimised or high maturity (CIC 2013, ARUP 2014, Succar & Kassem, 2015). BIM is classified as a number of different



levels of maturity, as shown in Figure 7 and the levels of maturity are explained as follows (GCCG 2011):

i. Level 0:

Unmanaged CAD probably 2D, with paper as the most likely exchange data mechanism.

ii. Level 1:

Managed CAD in 2 or 3D format using BS1192:2007 with a collaboration tool providing a common data environment, possibly some standard data structures and formats. Commercial data managed by standalone finance and cost management packages with no integration.

iii. Level 2:

Managed 3D environment held in separate discipline “BIM” tools with attached data. Commercial data managed by an ERP. Integration on the basis of proprietary interfaces or bespoke middle programme data are could be regarded as “pBIM” (proprietary). The approach may utilise 4D and 5D cost elements as well as feed operational systems.

iv. Level 3:

Fully open process and data integration enabled by “web services” compliant with the, emerging IFC / IFD standards, managed by a collaborative model server. Could be regarded as iBIM or integrated BIM potentially employing concurrent engineering processes.

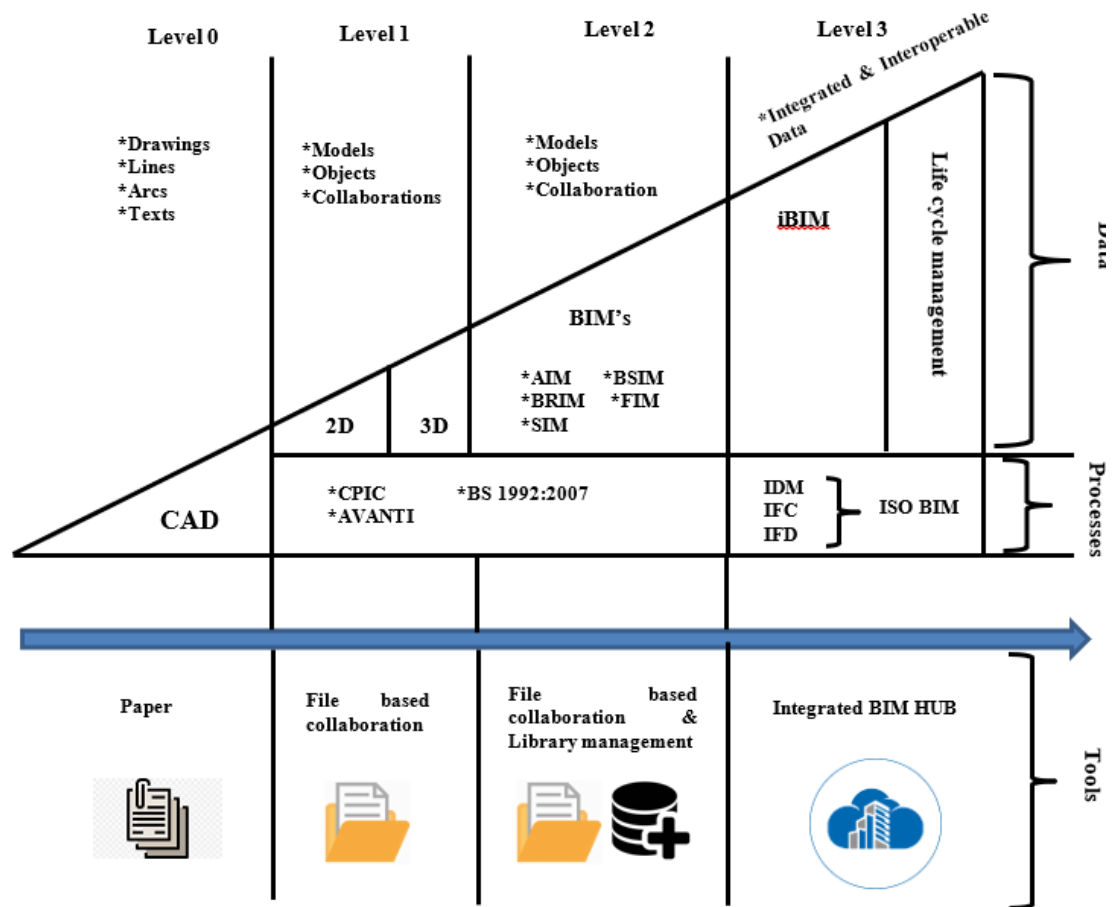


Figure 7: The BIM maturity model (Modified from GCCG 2011).

The main shortcoming of this BIM Maturity Model is that it's not exactly a maturity model for the served purpose of a usual maturity model. This can be considered more like a strategy model, a policy model or an industry roadmap. It is due to the structure and evolving definitions of BIM levels which render them unsuitable for assessing BIM diffusion across markets or BIM performance within organizations (Succar & Kassem 2015).

### Evaluation

The first BIM maturity measurement tool is NBIMS CMM, proposed by the National Institute of Building Science in 2007 as part of its famous National BIM Standard. The model evaluates BIM implementation in 11 areas using a 10-level scale (NBIMS, 2007,

Giel & Issa 2014). The final score of BIM maturity is calculated by the weighted summation of all areas

### 2.5.2 Digital twin

As per Forbes (2017), digital twins are powerful masterminds to drive innovation and performance. Imagine it as your most talented product technicians with the most advanced monitoring, analytical, and predictive capabilities at their fingertips (Forbes 2017). The digital twin is one of the enabling technologies, which has the potential to contribute towards the achievement of Industry 4.0 targets. According to the National Aeronautics and Space Administration (NASA), *'digital twin is considered as a multiscale, probabilistic, multiphysics, ultra-fidelity simulation that reflects, in a timely manner, the state of a corresponding twin based on the historical data, real-time sensor data, and physical model'* (Glaessgen & Stargel 2012). As per DebRoy *et al.* (2017) in a construction perspective *"A digital replica of additive manufacturing hardware, which integrates models for temperature, microstructure and properties, and residual stresses and distortion"* (DebRoy *et al.* 2017). Hence digital twin helps in time-consuming and expensive empirical tests to evaluate and analyse the effects of various process variables and plays an important role in the construction industry in general (Knapp *et al.* 2017, Zheng *et al.* 2019). This helps in the enhancement of product and service lifecycle management (Kritzinger *et al.* 2018, Tao *et al.* 2018).

Considering the advantages of digital twin, it is also often described as being one of the most "unrealistic" in recent years by a few authors (Tuegel *et al.* 2011, Tuegel, 2012, & Hauptert *et al.* 2017). Considering the explicit research conducted in the past on the challenges on digital twin by various authors, it can come to a consensus that the top five challenges are large database requirements, few uncertainty in the quantification of simulation results, lack of quality information across the organisation and input to distinctive models, and requirement of high computational power (Tuegel *et al.* 2011, Schleich *et al.* 2017, Grieves & Vickers 2017). According to a recent blog article by John Adams (2019), he states *"The real-world benefits of digital twins will be best uncovered through collaborative research and innovation, but themes are already starting to emerge"* (Adams 2019).

As it be seen that digital twin is being created from the virtual models of the physical objects to predict the environmental behaviour of the real-world these days including the construction industry (NASA 2014). Hence, it is considered as a two-way mapping process of virtual models and physical objects. Tao *et al.* (2017), has proposed that the comprehensive digital twin should be composed of five dimensions, physical space, virtual space, data, service and their connections which has been shown in Figure 8 (Tao *et al.* 2017).

- Physical space concept is going to imagine through the virtual space.
- The idea of virtual space created to support the decisions, and monitoring, controlling and simulating manufacturing processes.
- Further, the data of both physical-virtual parts are prerequisite to creating new information.
- Services in the digital twin have an ability to reinforce efficiency and accuracy in the engineering system.
- And at the end, the connection part is leading towards to create a way to link all the elements (physical-virtual-data-service) together in one system.

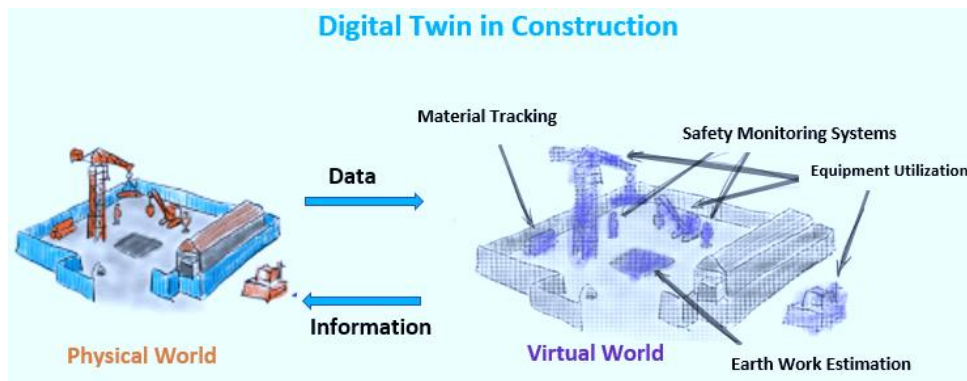


Figure 8: Digital twin process framework (Modified from Intellectsoft 2018)

#### *Digital Twin maturity levels*

The high maturity in the model sophistication shows that the control system for all purposes of discussion in the sense of a digital twin is still maintained (David 2018).

Madni *et al.* (2019) mention digital twin consists of 4 main levels of maturity that has shown in Table 3 (Madni *et al.* 2019).

i. Pre-digital twin level

In this level, prototypes were created during the upfront engineering process and help decisions making at the preliminary conceptual design level.

ii. Digital twin level

Level 2 is a digital twin in which the virtual system model has the capability of incorporating performance and maintaining data from the physical twin.

iii. Adaptive digital twin level

Level 3 is the Adaptive Digital Twin. It offers an adaptive user interface (in the spirit of a smart product model) to the physical and digital twins. The adaptive user interface is sensitive to the preferences and priorities of the user/operator.

iv. Intelligent digital twin level

This is an intelligent digital twin which includes all the current sophisticated technologies like unsupervised machine learning capabilities to discern objects and patterns encountered in the operational environment with a very high degree of autonomy. The following table shows the digital twin maturity levels with other characteristics as follows:

Table 3: Digital twin levels and its characteristics (modified from David 2018, Madni *et al.* 2019)

| Level                             | Model Sophistication  | Physical Twin  | Data Acquisition from Physical Twin  | Machine Learning (Operator Preference) | Machine Learning (Environment) |
|-----------------------------------|---|----------------|--|--|--------------------------------|
| <b>1 Pre-Digital Twin</b>         | Virtual system model with an emphasis on technology/technical-risk mitigation           | Does not exist | Not applicable   | No                                     | No                             |
| <b>2 Digital Twin</b>             | A virtual system model of the physical twin   | Exists         | Performance, health status, maintenance; batch updates                             | No                                     | No                             |
| <b>3 Adaptive Digital Twin</b>    | A virtual system model of the physical twin with adaptive UI                            | Exists         | Performance, health status, maintenance; real-time updates                         | Yes                                    | No                             |
| <b>4 Intelligent Digital Twin</b> | A virtual system model of the physical twin with adaptive UI and reinforcement learning | Exists         | Performance, health status, maintenance, environment; both batch/real-time updates | Yes                                    | Yes                            |

### 2.5.3 Integration of BIM and digital twin with AR/VR

As per Fraunhofer Institute (2019), building information modelling with a consistent and structured data management is the key to generate a dynamic digital twin of building whose dynamic performance can be studied by building simulation tools for a variety of different boundary conditions (Fraunhofer Institute 2019). Data management practices play a very critical role in making digital twin as efficient as possible since it can be focussed in detail on data analysis on a case by case basis (Cobuilder 2018). Also, as digital twin technology, AR also has rapidly gained attention worldwide (Rese *et al.* 2017). The following Figure 9 shows the representation of BIM and digital twin with the integration of AR technology.

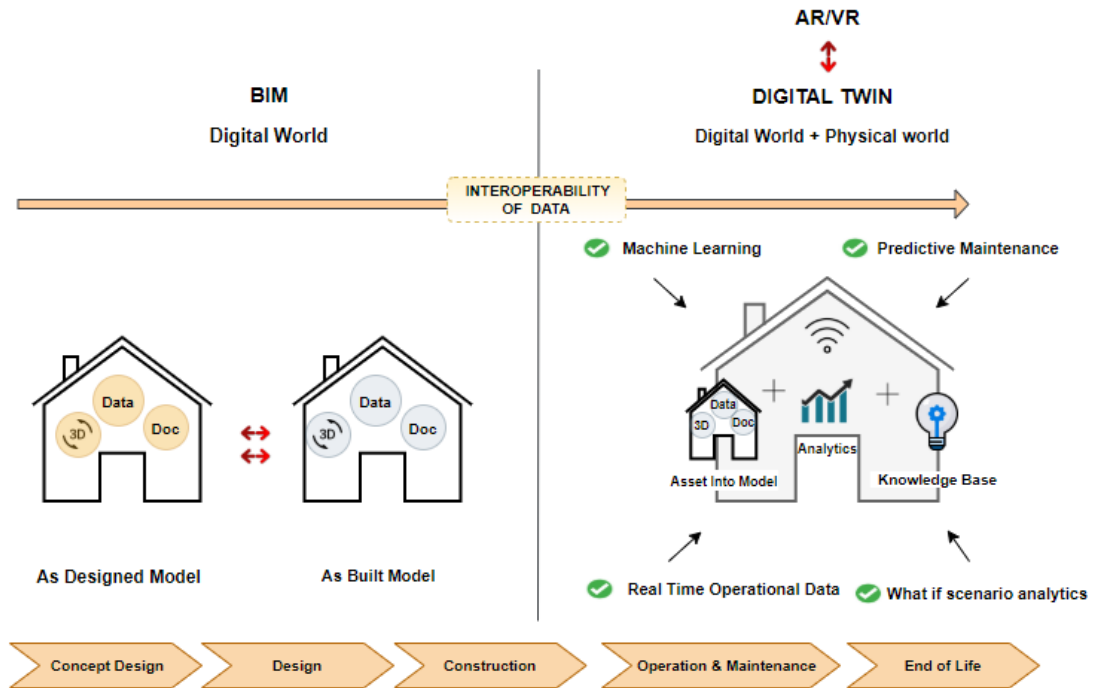


Figure 9: BIM and digital twin interconnection (Modified from Co builder 2018 & Lang 2019)

As per Havard *et al.* (2019) twinning virtual information model with the reality helps significantly in decision-making during each phase of the whole building's lifespan from manufacturing, design, construction, maintenance, operation, retrofitting to even demolition (Havard *et al.* 2019). By creating a digital thread from engineering systems downstream to quality assessment (QA) technicians during assembly, augmented reality experiences can be created and updated in no time when compared to hours or weeks via custom or labour-intensive reprogramming. Early research conducted in the 2012's by Yeh *et al.* (2012) used a basic construction helmet device in integration with a touch device and a small projector, which gave access for information from BIM models to be projected in front of the users (Yeh *et al.* 2012). Hence considering the emergence of AR and digital twin, the combination of the two can ease pain points associated with each technology and accelerate digital transformation (Lang 2019).

It is indeed a challenge to integrate BIM and AR as per research retrieved by some surveys conducted by authors and is said that workers found less effort in utilising 2D drawing and found it a tedious task on extracting information from BIM models (Chu *et al.* 2018).

In the integration of AR and BIM, retrieving information seems to be a challenge from the literature and it can be clearly understood that the combination of AR, BIM and DT can easily eliminate the pain points on the current challenges in the implementation of this technology in the construction industry.

#### 2.5.4 Augmented reality

Augmented reality is becoming popular these days and has been identified as a significant technology supporting industrial activities. The aim of the Augmented Reality (AR) is to increase human performance to accomplish specific tasks by providing the required information. It is considered as a Human-machine interaction tool that creates computer-generated information in the environment of the real world (Rentzos *et al.* 2013). Further, AR is also defined as the combination and alignment of real and virtual objects in the real world which Ability to interact with the 3D dimensions of the virtual object in a real-time (Alcácer & Cruz-Machado 2019).

The progression of augmented reality devices and its applications is being filtered into the construction industry. One of the most promising applications of AR can be seen in the construction maintenance field, where it allows to strengthen the human-performance to achieve optimized results in the execution of technical tasks. Also, it enables to assist decision making in the maintenance activities. E.g. HHD (Hand-held-display) can obtain maintenance tasks of the consumer devices by providing step by step guidelines in the assembly sections (Dini *et al.* 2015). AR expertise also plays an essential in the diagnostics sector by the use of HHD. HHD also to detect the defective papers in the constructed areas and allows operators to know the degree of defect, in order to take better decision to repair it in the optimized way (Leyh 2017, Alcácer & Cruz-Machado 2019). Moreover, the applications of AR can be found in a wide range of fields, for instance, manufacturing, maintenance, supply chain, health care, marketing, etc. (Palmarini *et al.* 2017). A study by Wu *et al.* (2013) mentions the challenges in AR as well such as the need for more well-designed interfaces and stable devices (Wu *et al.* 2013). Creation of more user-friendly interfaces is said to be a significant challenge for AR technology including usability and profitability of the hardware (Li *et al.* 2018 & Dini *et al.* 2015, Wu *et al.* 2013). Li *et al.* (2018) also point out challenges focussing in the context of the construction industry, where higher connectivity and interoperability of data between



AR-systems and other Information and Communication Technology tools are required (Li *et al.* 2018). In addition to this data protection and privacy (Vert & Vasiu 2015, Olshannikova *et al.* 2015), telecommunication tracking with ar and camera-resolution issues are still in its immature stage due to the lack of integration between other digitalisation systems with AR, (Palmarini *et al.* 2018, Siltanen 2012, Fraga-Lamas *et al.* 2018).

### 2.5.5 Enabling technologies

#### *Internet of things (IoT)*

Industry 4.0 is closely related to the “Internet of Things” movement, which also refers to a flexible and service-oriented computing infrastructure (Lopez research 2013). IoT is the connection of thing to thing, thing to human and human to human from any path/network connected through the internet, which allows individuals to exchange information within the existing network (Choi & chung 2017, Sadiku *et al.* 2017). The goal of IoT is to have a network which connects to the industrial environment on the basis of smart and enabling technologies to achieve real-time communication among devices and networks while having better, optimized and cost-efficient production systems (Cheng *et al.* 2018). Further architecture of IoT solution can be seen in Figure 10.

According to the Perera *et al.* (2013) and Madakam *et al.* (2015), “IoT enables things to be connected anytime, anyplace, with anything and anyone, ideally using any path, any network and any service”. The things in IoT are escorted with actuators, sensors or person and objects (Perera *et al.* 2013 & Madakam *et al.* 2015). The efficiency of Internet of things (IoT), to the large extent, is relying on the interconnection among various kind of “Things”, which have diverse storage and communication capabilities, and energy supply characteristics. (Sadiku *et al.* 2017, Sezer *et al.* 2018, Yang *et al.* 2019). Research by Davis (2015) provides evidence that digitalization of the factories with IoT proved to significantly decrease the number of errors and defects and improve the business process of the company (Davis 2015). At the same time the main challenges in the implementation of IoT as per Yang *et al.* (2019) extensive literature review and empirical survey were Estimations of ROI, cybersecurity, robust connectivity, cultural resistance and structural management problems Yang *et al.* (2019). These IoT challenges, especially in the

modern-day privacy and security issues were validated by many other researchers as well from various geographical locations and industries (Li *et al.* 2015, Madakam *et al.* 2015, Sezer *et al.* 2018).



Figure 10: Architecture of IoT solution (Modified from Chiang & Zhang 2016, Tomic 2017, Reja & Varghese 2019).

### *Fifth-generation network (5G)*

As discussed in the above section, one of the challenges of IoT is the need for faster, reliable, robust connectivity network. 5G is one technology that can solve this issue (Reja & Varghese 2019). The construction business in the recent past has been an advanced transformation in technologies that have been applied in building techniques, scheduling, materials, wireless data communication, and collaborative platforms such as BIM. Within this domain, 5G is said to improve and enhance bandwidth making ultra-high-definition videos available through AR/VR (augmented and virtual reality) and drone technologies, which also open doors in ensuring machines that receive signals, inputs, receive input, and shared communication in fraction of time because of 5<sup>th</sup> generation network (5G) (NECA 2019).

Moreover, 5G will help future factories by providing integrated communication platforms which could be adopted by the various business models and also resolves the shortcomings issues in the current communication technologies. (Rao & Prasad, 2018, Jovović *et al.* 2019). On the other end implementation of 5G is still in the immature stage for the following reasons like Interoperability and standardisation challenges to meet standards (Ahmad *et al.* 2018), Cross-industry collaboration and mainly Ultra-Responsive connectivity (Rao & Prasad 2018, Simsek *et al.* 2016) with unprecedented requirements on delay and reliability (Simsek *et al.* 2016). Further due to data sensitivity these days, 5G security challenges in Cloud and user privacy plays a huge impact (Ahmad *et al.* 2018)

### *Cloud Computing*

There are various definitions for cloud computing and one of the concrete definitions is given by the national institute of standards and technology (NIST), which states “*Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction*” (Wang *et al.* 2017, Mell & grance 2011). Cloud computing is the technology which has been a major technological trend in recent years and has made the production system much smarter and flexible that has sharpened the way of modelling businesses (Alcácer & Cruz-Machado 2019). It has attracted a lot of attention as a feasible alternative technology which provides a broad range of data storage facilities to the traditional companies, who are privately spending on the outsourcing IT services (Assante *et al.* 2016). Also, cloud computing is a kind of digital data software which provides services, like data storage, data management, data analytics and data visualisation (Yang *et al.* 2019).

In order to improve the traditional manufacturing environment, cloud manufacturing concept was introduced, which allow to utilise the cloud computing technology. Cloud computing in manufacturing provides, various web-based or computer-aided applications for production activities which can directly be utilised in the manufacturing environment from a cloud system (Wang *et al.* 2017). However, like the IoT technologies, cloud computing also comes with major challenges on the absence Standardisation because of

the probable bottleneck of different technologies and the usual security and data privacy issues where extensive research has been conducted (Islam *et al.* 2013, Assante *et al.* 2016, Wang *et al.* 2017, Tao *et al.* 2014). Another set of challenges mainly rises in data lock-in and data segmentation, where lack of application programming interface (API's) restricts its application and services between clouds and also lack of data segmentation can bring in risk to properly separated storage between different users in a single platform (Saharan & Kumar 2015).

## 2.6 Literature synthesis

### 2.6.1 Synthesis on robotization

Considering the first principal researched topic on “Robotization”, this researched phase brings light to the importance of robotization in the construction industry and the impact it produces in the entire construction process. From the theoretical foundation, it clarifies how traditional methods and practices in construction processes are facing challenges while attempting to be productive and also relating to system effectiveness. Therefore, innovative directions would be needed for traditional systems through robotic and automation technologies (Gambao *et al.* 2000). Typically, robotics and automation can be utilised in two different sectors, civil infrastructure like earthwork, tunnel, roads etc. and house building sectors like, modular industrialised building's construction, interior building finishing, concrete compaction etc. (Balaguer & Abderrahim 2008). Due to the advancements in robotics, digital software, and smart technologies have allowed a new wave of automation in the construction industry (Higgins 2019). However, a researcher from the University of West of England (UWE), has stated that robotics technology has a significant potential to bring economic benefits to the construction industry, but due to the complicated industrial framework, the likelihood is towards the lower adoption of the robotization (Delgado *et al.* 2019). Further, the key findings from the literature review on robotization are synthesised in Table 4 and provide the currently available research conducted by various authors with the findings that can be utilised to be validated in the empirical research.

The current market trends and statistics researched in the literature review clearly shows the improvement in market trend in robotization in the construction process with government bodies making robotization a compulsion. In addition to which global shipment of only construction robots has currently reached \$16.5 billion in 2018 and is forecasted to grow 12% per year until 2022 (IFR 2019, Market research future 2019). However, considering the market in collaborative robots, as per IFR (2019), there was a very small percentage improvement in the global installation of collaborative robots between the years of 2017-2018, despite the advantages (IFR 2019). Considering these trends and the findings in Table 4, one part of the RQ1 is answered. Industry 4.0 aims to connect the physical world with digital technologies to get a high-level of operational productivity and efficiency in the industrial processes (Wagner *et al.* 2017, Weyer *et al.* 2015 & Peruzzini *et al.* 2017).

Table 4: Synthesis findings on robotization and prefabrication

| Potential Benefits of Robotization   |  |
|--|--|
| <ul style="list-style-type: none"> <li>Enhance Product Quality</li> <li>Quick Redeployment</li> <li>Improves Work Quality</li> <li>Fulfil Demand on Time</li> <li>Faster Production Cycles</li> <li>Agile Learning</li> <li>Reduces downtime</li> <li>Safety and Health of worker</li> <li>Standardised Work Procedure</li> <li>Coverage the shortage of labour</li> <li>substantial reduction of project lead time</li> <li>Reduces risk to damage product</li> </ul> | <b>References:</b><br><br>Eversmann <i>et al.</i> (2017), Bier (2018), pp.49, Asplund & Brile (2017), Steidel (2019), Afsari (2018), Ryymin <i>et al.</i> (2019), Schou <i>et al.</i> (2018), Salmi <i>et al.</i> (2018), ETH Zurich (2018), Steidel (2019), Helm <i>et al.</i> (2014), Bakir & Balchi (2018), Vasey <i>et al.</i> (2016). |
| Potential Challenges of Robotization in large scale assembly   |  |
| <ul style="list-style-type: none"> <li>Portability of machine</li> <li>Robotics software framework</li> <li>Fault tolerance</li> <li>Programming</li> <li>Cybersecurity issue</li> </ul>   | <b>References:</b><br><br>Hentout <i>et al.</i> (2018), Matthias <i>et al.</i> (2011), Delgado <i>et al.</i> (2019), Bier (2018), pp.49-55, Maurtua <i>et al.</i> (2017), Ardiny <i>et al.</i> (2015), Schou <i>et al.</i> (2018)  |
| Benefits of Pre-fabrication activities   |  |
| <ul style="list-style-type: none"> <li>Time savings</li> <li>Reduces costs</li> <li>Higher productivity levels with enhanced quality</li> <li>Reduces construction waste</li> <li>Standardisation opportunity</li> <li>Green construction objectives</li> </ul>  | <b>References:</b><br><br>Singhai (2015), Kutuba, T. (2017), Wu (2017), Zhang <i>et al.</i> (2014), Dainty <i>et al.</i> (2005), Paudel <i>et al.</i> (2016)   |

| Challenges of Pre-fabrication activities  |   |
|---|---|
| <ul style="list-style-type: none"> <li>▪ Difficulties in the design change</li> <li>▪ The initial investment for implementation</li> <li>▪ lack of expertise availability</li> <li>▪ Larger lead-time</li> <li>▪ Space limitations</li> </ul> | <b>References:</b><br>Vähä <i>et al.</i> (2013), Alonso-Zandari & Hashemi (2016), Kutuba, T. (2017), Li <i>et al.</i> (2016), Bock & Linner, pp.12 (2015) |

### 2.6.2 Synthesis on digitalisation

Digitalisation in this thesis is considered from the point of view of the construction industry by utilising Industry 4.0 technologies that can help to enhance the productivity of the construction manufacturing processes. Industry 4.0 aims to connect the physical world with digital technologies to get a high-level of operational productivity and efficiency in the industrial processes. (Wagner *et al.* 2017, Weyer *et al.* 2015 & Peruzzini *et al.* 2017). Table 5 gives a brief synthesised explanation of the important aspects of Industry 4.0. On the other hand, the literature review puts in light the ways to integrate DT, AR and digital design knowledge and mentions maturity models of BIM and a digital twin which can be utilised to study the maturity levels of the organisation and provide necessary recommendations with a clear roadmap framework (Fraunhofer Institute 2019, NBS 2019, Madni *et al.* 2019). Enabling technologies like 5G, IoT VR/AR, and cloud computing play an important role in supporting technologies like digital twin and BIM. The pros and cons of these technologies are mentioned in their respective sections. Further, it can be clarified from the literature review that digitalisation in the businesses can bring benefits to their value chain while connecting with smart technologies at every aspect like, interacting with the information and communication technologies and their digital tools and methods (Roland berger GmbH 2016). Moreover, information is an important asset in the construction business, as decisions are taken based on the quality information available. Thus, the flow of information can be managed through data management which is highly significant in the construction processes (Caldas *et al.* 2005).

Table 5: Synthesis findings on digitalisation

| Building Information Modelling (BIM)   |   |  |
|--|---|--|
| Definition: BIM is defined as the most promising and powerful technology which provides robust design management tools to the Architecture, Engineering & Construction (AEC) industry (Yan & Demian 2008). Typically, it is considered as a process for creating and managing construction-related information throughout the project-lifecycle (Ghaffarianhoseini <i>et al.</i> 2017).  |   |  |
| Benefit on business  | Major challenge   | Examples/Application   |
| <p>Real-time monitoring of ongoing project satisfies potential stakeholders (Neves <i>et al.</i> 2019, Cecconi 2017, NBIMS 2007)</p> <p>Helps in improving the efficiency of operating costs (Latiffi <i>et al.</i> 2015, Correa &amp; Maciel 2018, Marzouk <i>et al.</i> 2018, Ahn <i>et al.</i> 2016, Eastman <i>et al.</i> 2011)</p> <p>Improves the accuracy scheduling, designing and budgeting aspects in construction projects (Latiffi <i>et al.</i> 2016, Ganah &amp; John 2014, Alaloul <i>et al.</i> 2018, Correa &amp; Maciel 2018)</p> <p>Facilitating visualization and simulation of the construction process (Marzouk <i>et al.</i> 2018, Trani <i>et al.</i> 2016, Becerik-Gerber <i>et al.</i> 2011, Furneaux 2008)</p> <p>Provides a common integrated digital platform and makes the process much flexible (Vilutiene <i>et al.</i> 2019, Furneaux 2008, Li <i>et al.</i> 2017, Jiancheng, L. (2012)</p> | <p>Investment cost hindrance in the implementation of BIM (Sun <i>et al.</i> 2017, Ghaffarianhoseini <i>et al.</i> 2017, Ganah &amp; John 2014,)</p> <p>Lack of technological readiness level (Juan <i>et al.</i> 2017, Porwal &amp; Hewage 2013, Dong <i>et al.</i> 2014)</p> <p>Lack of training and knowledge in BIM (Tulenheim 2015, Porwal &amp; Hewage 2013, Dong <i>et al.</i> 2014, Gheisari <i>et al.</i> 2016, Won <i>et al.</i> 2013, Ganbat <i>et al.</i> 2018)</p> <p>Lack of data interoperability (Maskuriy <i>et al.</i> 2019, Neves <i>et al.</i> 2019, Dong <i>et al.</i> 2014, Cao <i>et al.</i> 2015)</p> | <p>Project Visualisation to the key investors (such as clients, engineers, facilities and contract Mangers etc.) (Sun <i>et al.</i> 2017, Vilutiene <i>et al.</i> 2019)</p> <p>Early design and build concept, save project time and capital (Vilutiene <i>et al.</i> 2019, Furneaux 2008, Li <i>et al.</i> 2017)</p> <p>Precise 3D Model for project-lifecycle (Latiffi <i>et al.</i> 2015, Hou <i>et al.</i> 2014)</p> <p>Project Scheduling through BIM software (Autodesk, Latiffi <i>et al.</i> 2013, Ahn <i>et al.</i> 2016)</p> <p>Facility Management capabilities like, provide maintenance to constructed buildings. (Miettinen &amp; Paavola 2014, Correa &amp; Maciel 2018)</p> <p>Cost estimation of Projects via BIM software. (Sun <i>et al.</i> 2017, Khosrowshahi &amp; Arayici 2012)</p> |
| Digital Twin (DT)  |   |  |
| Definition: As per (Hauptert <i>et al.</i> 2017) and Grieves (2014), Digital twin considered as an object which has integrated data of the virtual information model of the physical world (Kritzinger <i>et al.</i> 2018)   |   |  |
| Benefit on business  | Major challenge   | Examples/Application   |
| <p>Enhance Product and service lifecycle management (Kritzinger <i>et al.</i> 2018, Tao <i>et al.</i> 2017)</p> <p>Real-time Data Mapping, storage and processing capability and time-saving benefits (Zheng <i>et al.</i> 2019, Knapp <i>et al.</i> 2017)</p>   | <p>Difficulties in integrated diverse technologies (Knapp <i>et al.</i> 2017)</p> <p>Large storage and base requirements (Tuegel <i>et al.</i> 2011, Schleich <i>et al.</i> 2017, Grieves &amp; Vickers 2017)</p>   | <p>Allows details diagnosis of the manufacturing activities (Kritzinger <i>et al.</i> 2018)</p> <p>Digital twin system monitors real-time assembly shop-floor, automation line, welding lines etc. (Zheng <i>et al.</i> 2019)</p>  |

### 3 CURRENT STATE ANALYSIS OF DIGITALISATION AND ROBOTIZATION IN THE CASE COMPANIES

In this section, the current state analysis of the case companies has been explained, which is based on the literature view findings that allow accessing the current robotization and digitisation practices in the construction companies. Further, this section explains the key loopholes in the context to adopt digital activities in the case companies. Also, in this segment, the empirical research process and characteristics of the interviewed case companies have been discussed in detail. The other sub-chapters deal with the procedures of the outcome on the empirical results of all the four case companies.

#### 3.1 Empirical methodology

Semi-structured interview and survey process were used for this study, and the process is shown in Figure 11. Based on the research questions and objectives of this thesis, interview questions were created in two parts. The first part includes the semi-structured questions and the second part includes the short survey questionnaire as shown in Appendices A & B. The primary aim of the semi-structured questionnaires is to get the detailed information on the construction process, robotization, building information modelling and supporting enabling technologies practices in case companies. On the other hand, the survey was to collect quantifiable data and validation data to the literature review that was relevant to focus on current state analysis of the companies.

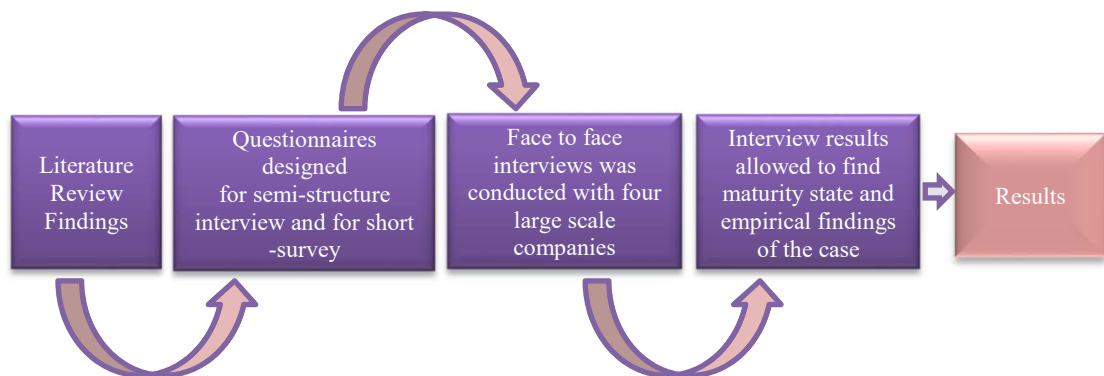


Figure 11: Empirical research process



Further, four face to face interviews were conducted at four large-scale companies. All the interviews were arranged by higher management personnel of the company. The short summary of case companies and the role of the interviewed personnel are shown in Table 6 below. In order to conduct the empirical research, it was planned to select large leading companies in Finland where company's experience and skill to perform construction tasks allow to get a broad view on how digitalisation activities are carried out in the scaled company. Thus, the combination of semi-structured interviews and the short survey questionnaire plays a significant role to gain detailed information about the insight's digital design knowledge and robotization practices of case companies.

Table 6: Characteristics of the case companies

| Case Company's | Company size               | Main Business                                | Interview Duration | No. of Interviewees | Role of the Interviewees                               |
|----------------|----------------------------|--|--------------------|---------------------|--|
| A              | Large Scale Company        | Construction building & civil infrastructure | 1 hour             | 1                   | Vice President   |
| B              | Large Scale Company        | Prefabrication construction company          | 1 hour             | 1                   | Chief Development Officer                              |
| C              | Large Scale Global Company | Construction building & civil infrastructure | 1 hour             | 2                   | Head of BIM and Digital services & Development Manager |
| D              | Large Scale Company        | Leading Log-House manufacturer               | 1 hour             | 1                   | Technical Director                                     |

#### Background information of case companies

##### *Case Company A*

Case Company A is one of the biggest construction companies in Finland and also a big player in the Northern European region. They are specialised in designing and building homes, commercial premises and whole infrastructure construction areas. They have nearly 8000 professionals who are contributing their knowledge and skills in order to create smart, sustainable and attractive cities and environments in ten countries.

According to them, sustainable development means that the productive way of using natural resources, innovative and restoration of the existing urban areas and efficient use of circular and distribution economy models with the latest technologies.

#### *Case company B*

Company B is one of the well-known construction group in Finland, which consists of 1300 employees. It has developed its operations by focusing on economically oriented building models. Their economical construction models allow them to integrate from the design to the implementation process, which brings cost benefits and reduces unnecessary delays. Further, they have decades of experience in the designing, renovating and construction activities. The company has achieved construction innovation developed through a prefabricated modular system. The system not only provides cost savings but also enhances the quality of construction activities.

#### *Case company C*

Case Company C is a large international company and also a leading construction group that offers various construction projects in the entire world. In Finland, they are offering various services and development projects for residential, commercial and civil construction activities. They have long working experience to contribute their share to build a more sustainable world, as they are developing and upgrading a more safe, responsible, and efficient work culture for their employees, partners and clients. The company has around 2000 employees in Finland, which are contributing their knowledge and skills in order to provide advance knowledge and solutions of construction projects to its customers.

#### *Case company D*

Case Company D is a Finnish company and has 227 professionals, who are contributing their work to build high-quality log-houses to their clients, builders and architects across 20 countries. They are claiming that they are the leader in log house industry. According to the company's strategy, they are continuously developing their technical understanding and introducing innovative technologies which help to create massive wooden buildings

with a high level of quality. Around 20% of their products are sold to other companies, and their main customers are from Japan, France and Sweden.

### **3.2 Current practices in case company A**

#### *Robotization in construction*

Company A is not mainly using robotization technologies in construction prefabricated activities. The main challenge they feel is that it is difficult to utilise sophisticated robots for their kind of market category that is mainly focussed on housing, hospitals, schools, offices, etc. However, company A does utilise robots in the construction site and mentions digital cranes, tractors, jumbo drills, excavators, grouting vehicle and other digital machines which are key potential machinery or equipment's which cannot be avoided in the construction site. On the other hand, in their factories, they utilise digital CNC machines, smart elevators, forklifts, digital cranes, etc. for their production activities.

Even though the company is not utilising high-level robotization in the pre-fabrication process, still they produce several types of modular elements for the roof, wall, bathroom, balcony, outdoor structure, slabs, insulation, ventilation, and other housing elements in an economical way. They believe that pre-fabrication process helps in delivering superior quality material, high reliability, and high efficiency with the least amount of time-consumption. Further, the organisation believes that utilisation of robotization will enhance productivity and reduce stress on human-work. Perhaps five years later once their market segment or category expands, they will find the need to utilise sophisticated robots in their construction prefabricated activities, mainly in their factories.

Since the company also works in cold environments and in a dynamic competitive world, the need for robots is inevitable according to the company. Also, uneven and unstructured sites bring various challenges for robots to perform their tasks. Hence there is a need for high-level robotization within the company in the future as per company A, and they believe there is a potential benefit in the future. However, one major challenge that exists is fear in the increase in the unemployment rate of factory workers. Thus, even though the benefits are known by company A the challenges also need to be weighed in order to implement robotization in company A.

### Building information modelling

According to the case company, building information model (BIM) has been utilised in all their housing projects. They believed that BIM has boosted their construction activities in many ways. It added speed, efficiency, and reliability of their projects. From their perspective, BIM is a kind of technology that has the ability to collect the data, improves the flow of quality information and convert information into the visual and geometric models. Also, they believe that it is not just the ordinary model which transforms the traditional design into 3D, but it is a model which can bring better use of the prefabricated products and standard components. As there are so many methods and techniques being developed in the construction industry which are non-standard from start to end. However, BIM brings standardisation solutions for standard components and prefabricated products.

Further, they are utilising various types of planning methods like; 2D drawings, 3D models, 3D BIM and 4D BIM in several phases of the construction projects. In practice, company A is trying to create a precise digital model of the building before the start of physical constructing. They are creating BIM models for architecture, construction, electricity, heating-ventilation- and air-conditioning (HVAC), etc. These models bring significant values in building design, construction and maintenance phases. Alongside excavators, site-huts and cranes, BIM has also become a prominent part of their construction sites. It allows to facilitate in every stage of the projects, from the organising plan, preparing schedules, estimates costs, planning sales and marketing strategies and further development stages. According to them, it can be viewed that the BIM model also has competitive edge in-order to manage the lifecycle of the building projects.

Moreover, they explained that day by day learnings and current requirements of the industry allow them to update their system by time to time. They think BIM is the lifeline for their construction projects because, without BIM, it would be difficult to save resource, fulfil the projects on time and with high efficiency. From their own experience, BIM is also a highly effective tool for alliance construction projects. One of the alliance-project was to build a school had achieved great success. The model was really useful in all the construction phases, and it allowed to fulfil all the customers' expectations. Company, clients, users, and the main contractor were all satisfied with the end results.

However, they think that the next steps in-order to improve their BIM model will be the integration of the existing model with the digital twin applications. Though it would be a challenge in their context, but successful integration will bring a big impact on the new projects.

#### Data management

Besides that, the company has a centralised management system and several support systems. Company has centralised data-hub, which brings data from all the business units into the one platform, according to the vice-president of the company. It allows, company to have access on real-time data which helps them to perform better decision making, faster reporting and improved service quality. It also enables to create new products and services and brings new opportunities to predict better sales and future projects. Further, they are using GRIP management system which has introduced it recently in their company. GRIP has the traditional ways of smart working style, and it is also suitable for their company's culture. Further, the company is paying more attention on managing their data as they believed that their data management system is a critical strategic tool for them which drives everyday operations effectively.

#### Supporting enabling technologies

From the interviewer perspective, digital technology solutions have reduced the traditional way of doing the paperwork at the construction sites. According to the case company A, enabling technologies, like digital twin, AR/VR, IoT, and cloud computing are already playing a significant role in the construction activities. The integration of these technologies allows to develop the smart way to design, construct and maintain the building projects more efficiently. The tremendous amount of data generated from these enabling technologies opens new opportunities to enhance the enormous performance leap in the construction industry. The data is being optimised before and after the completion of construction projects. They believed that from the critical data, a digital twin can be made for the building which can be used during construction and, also for maintaining and renovating activities of the building in future. In their opinion, digital twin is a tool that allows to have a virtual and physical model of the building, which has an ability to work as a smart way to improve the overall lifecycle of the building projects.

Further, they think that digital twin also enables to reduce the workload at the construction sites. For example, when company can create a precise digital twin of the building elements like walls, roof, bathroom etc., these elements made with the accurate measures and can be delivered as a prefabricated component to the construction sites that allows to reduce the installation time.

Also, they believe that the integration of technologies, like an integration of digital twin with AR/VR will be beneficial to perform the maintenance tasks and it also allows to monitor the current status of the building. In their lifecycle projects, they have around 20 years of responsibilities to maintain constructed building. With the integration of technologies, it will be valuable to have the real-time monitoring of the building, in the case of any issue like water leakage etc., they can quickly take the necessary measures to stop it.

Further, they don't have current technologies/tools which can remotely measure the CO<sub>2</sub> level in the rooms. In-case the CO<sub>2</sub> level is low then they cannot adjust it from the remote access. So, it is the challenge for them these days. However, in winter times, sometimes temperature varies between the walls of the rooms. Nowadays, when speaking about energy efficiency, companies also consider CO<sub>2</sub> emissions and will try to make the emission as low as possible. Perhaps to manage such type of optimisation issues, they believed that apply advance digitalisation solutions which not only solve the issue but also bring high accuracy results in future.

Moreover, the company has a large cloud database system, where all the data like, models, drawings and such are stored in the cloud. The whole system is accessed through cloud services. However, due to the large amount of data generated day by day, they probably need huge data-space where they can store their data easily. Because some time they feel difficulties to store the data. Like, their models are very big and, more and more information are being added into it than it is hard to access in real-time. They probably need user-friendly and high data storage system in future which could flexible to store files.

According to the case company, the integration of enabling technologies are challenging for them. However, they believe that the integration and virtualisation of technologies

and smart intelligence solutions are not be designed in the blink of an eye. The proper groundwork is needed to build and implemented in the construction activities. These days they are in the planning stage, where they are analysing that which advanced technologies and their integration would be needed to enhance the lifecycle of their products and services. Currently, at the end of every project, they are examining which technologies should be needed in the next project that will bring the best results as compared to the previous ones. They further added that probably after five years' timeframe, they will use smart technologies quite efficiently for various purposes.

### **3.3 Current practices in case company B**

#### *Robotization in the construction*

Chief Development Officer (CDO) of the case company B, stated that human skills have not developed in the construction industry within the last forty years. Thus, in that industry, the utilisation of robotics technology would be vital. Company B believes that construction robotics has the potential to bring significant advantages to the construction industry. However, they assumed that good modular products are needed so that they can be robotised in assembly work in the factory and can be utilised on the construction site in order to bring productivity impact.

However, they proposed that standardised products should be needed to fully utilise robotics technology. They further explained that if the company does not productise their products in a modular way, not standardising the materials, sub-assemblies and main assemblies, then there is no means to use robots in the prefabrication activities. Thus, everything is about the productization and high volume of production. As the volume of the specific products need to be high enough so it can be done through robotization.

Further, the case company still needs a couple of years to fully implement robotization technology in its construction activities, as they need some time to adopt robotic knowledge to produce their products in a modular way. They are mainly using CNC machines within their factories to perform construction modular tasks. According to them, CNC machines are their current robotization practices at that moment. They don't

have bar robots which are the typical definition of the robots. Further, they have defined modularisation through the following steps:

- Materials (materials which are used based on the activities)
- Roof, Wall, Floor elements
- Space elements (8mX4mX3m)
- Room layouts, 1R, 2R, 3R apartments
- Type houses (six stories, four stories house)

These are their general modular structure that has been implemented in the factory related products. On the other hand, they have products that are assembled in the construction sites. They have those kinds of products, which can pre-productise the material and elements, but they cannot pre-productise space and layout of the houses and the type-houses. However, they believed that wooden houses, the wooden school can pre-productise with these five steps. They are also running a R&D program to build six stores kind of wooden house so that they can bring six stores of building as a prefabricated industrialised product.

Moreover, they believe that the company will fully utilise robotics technology probably after five years. Once they have robust product design or robust kind of factory methods and high knowledge towards digitalisation techniques, then they may have a situation where they may invest in the robots in the assembly cells. Currently, modularisation of the products is too early for them and they need to be very steady in productization and modularity. That is the main reason that prevents them to invest in the robotization in the current environment.

### *Building information modelling*

According to the case company B, the construction areas like infrastructure, roads and streets were the primary application of BIM model about some 15-20 years ago, and the BIM modelling for the housing and premises itself is a bit younger. It has a history of about ten years of having BIM modelling for the architecture, heating-ventilation- and air-conditioning (HVAC) and finally modelling for the construction activities. They



believed that the BIM model has brought workflow efficiency for several construction areas. According to them, BIM is the 3D model which can be utilised in various construction areas. However, as per literature review, the exact definition of BIM was not the same for the company.

The case company is using most of the all possible kind of BIM modelling applications. They have several CAD design tools for the architecture, construction, designing, electricity, water piping and HVAC. They do 2D, 3D and 4D BIM at that moment. According to them, 4D BIM is the extension of the 3D model, as the 3D model of the house and 4D means that they can do time scheduling of the assembly work based on the 3D modelling. Further, they are also utilising the 5D BIM means that they can manage the cost of the project. Further, the 4D (work sequence) is typically managed by the project management applications. So, based on the 3D model they can decide the work scheduling of the project and operations/scheduling of their projects.

Further, they believed that the current challenge in the construction business, what comes to BIM and CAD tools is depending on the design areas. Generally, in the construction area every design depends on its own CAD tool. The architect and construction designer, ventilation and electricity designer, have their own design systems which create difficulties in integrating all the designs into one BIM model. For example, architecture models are not fitting into other construction areas, not fitting into the piping and electricity models, and the correction to be done based on the alteration between the designers.

However, their company is advanced in utilising the traditional BIM modelling, but additionally, they are also looking for the solutions which can evaluate that instead of using several BIM applications they could have only one integrated system, like in the real industry. However, this will be a big change in the construction industry because no-one has the traditional and ideal model based on one CAD application that could design the whole product, but this is possible today. Moreover, company B believes that the main challenge in the construction business is to change the whole thinking from the construction design to modelling. Like, the challenge in the construction industry is so far that everybody has thought that every single house, business premises, office and hotel are one and unique. Staring from the unique thing that they always select that who is the

architecture, construction designer, HVAC designer, and then select the unique team who will successfully implement it in the construction site, thus everything is unique in the construction activities according to the chief development officer (CDO).

### Data Management

Company B mentions that they have a data management system which as being continuously developed and integrated into the main applications. This data management system has been integrated into sub-data management systems like

- Human Resource = HR master data system
- Customer data = CRM (customer relationship management)
- Product Data = Implemented PLM/PDM applications for the product master data.

Also, from the project master data point of view, they have several tools, and the idea is that the project master data application is the same as the product data. Then for the manufacturing-related production control, and work shifts sequence - they have management execution system (MES). Earlier, for the design master data and product master data, they used to have excel and PowerPoint applications. However recently they have PDM and PLM utilised in their system. Further, they are also developing the road map for what particular kind of product and project is going to be used in the product data system and in the centralised master data management system. They consider this to be a tedious task and mention that it is estimated to take four years to completely implement it.

### Supporting enabling technologies.

In the construction industry, the digital twin is the virtual model that looks the same as the real model without functioning at all. It can be simulated, but not performing the real functionality. Thus, simulation is not enough in the digital twin. According to company B, in the construction business, the product is very physical and typically there is not much software and automation that were utilised earlier, but today they have software for the automate lighting, locking system, fire alarm, security system, etc. In this context, according to the CDO digital twin means that first, they should test the locking system in

the virtual model before applying in the real product. However, construction activities of the case company are still far behind the ability to test the functioning of the product based on the digital model. It would be needed but they are not at that level. On the other hand, they believe that the digital twin can be seen as the 3D mode, as they are using 3D model based on their construction activities. Like for instance designing all constructing site of the building house is done through the 3D model, if it is considered as digital twin then they are using it.

Further, the case company also utilise VR applications from the marketing and sale perspective. For example, they have a VR application in which the real model of the building can be seen in the real-location through VR glasses by the customer. It fulfils the customer's expectations and allows them to increase their sales. However, they are not using AR/VR applications in the real construction process. But probably in the future, they can use it in the installation and maintenance activities to manage the life cycle of the product.

The case company is also using IoT and cloud computing technologies mainly for repair services and remote access to the houses, by the collaboration with their sub-contractors. All the data generated from the IoT devices can be stored in the cloud. The limited integration of technologies with the digital model helps them in the improvement of construction process performance of their built houses, care-centres, school, etc. The digital model means that they have a 3D model of the house, and in real-time, they can see the temperature, ventilation, lighting of the house and they can remotely adjust it as well. But for the remote excesses, they are cooperating with a service provider company.

However, the biggest challenge in fully utilising the enabling technologies is that they have fragmented digital models of the house, they have separate models for architecture, construction engineering, piping, ventilation, and electricity model. It is a real challenge in this industry that the product information is not being centralised and this is the thing they trying to be better and be own competitive advantage. If the flow of information is fully centralised than it will be the same information for the R&D, product design, manufacturing (factories), construction site workers, and maintenance workers. Thus, the biggest challenge is the fragmented production information at the moment.

### 3.4 Current practices in case company C

#### Robotization in the case company

The company is not mainly utilising robots in their production activities. The reason, why robotics is not fully being utilised yet is due to the data that is needed for robotization is being rather low quality and in silos. This brings very low possibilities for utilising robots in their activities. However, their subcontractors are utilising advanced robots to perform modular and prefabrication activities. For example, in one of the hospitals building projects, the company bought modular bathrooms from their subcontractors which are partially done by robots. It's just in one project but not utilised in a larger scale.

Further, the company is using robotics applications but not utilising them in an advanced way. But for example, on a civil site, they are using robotics machine control. When they get the models for civil works, the robotic applications within the machine can perform tasks automatically. This is an example where robotics solutions are being utilised mostly in their processes. Also, the robotics system is utilising in administration, procurement, and other processes.

Moreover, the case company observed that in recent years when the economy has gone up the level of prefabrication has been a bit lower. However, they believe that prefabrication activities are still popular and cost-effective in the current market situations. In the case company's headquarter they have HVAC (heating, ventilation, and air conditioning) modules which can be integrated into one modular system. Further, the company is using the BOKLOK module system which is mostly dominated by modular design, according to them. It is the housing building system for subsidiary buildings with high quality, good design, and truly at the low price of a house. It is a nice paradigm housing concept that is developed by the case company and its main subcontractor. For the past ten years, they have been applying the BOKLOK modular system in their prefabrication construction activities. For certain products, some parts of the modular systems are made from industrial automation but they cannot be considered as robotics yet.

Further, they are updating their new strategic policies for adopting new automation and robotics solutions towards the larger utilisation. The main motive to adopt these kinds of solutions is to improve safety at the workplace as they said safety is the main priority of the case company. Also, these solutions may help to reduce the stress on human workers and allows robotic technology to perform the dangerous construction tasks.

Furthermore, the case company C is also facing challenges in upgrading the automation technology and in adopting robotics in their production activities. They said the data management challenge during the design of the production is the main obstacle. Like they do not have enough and accurate data to utilise the robotics. They believe If they do not have an actual amount of data than it is not possible to use robotization. Moreover, they believe that the initial investment is also a challenge and it can be considered as an industrial challenge as well. Because the construction margin is not really high and they do not receive any benefits for the R&D activities. Further, they also think the following are challenges of utilising the robotization;

- How are they able to do the agile test of the new robotics solutions?
- Are they able to define a way that utilisation of robots are a scalable thing?
- Do the utilisation of robotics should be scalable or sustainable in the future. If it is not then it will be a negative investment.

According to the case company C, these challenges can be resolve by performing more agile ways of doing their R&D activities together with the collaborative partners. They believe that collaborative partners are really important here. However, it is quite challenging as well to find the right partner for their R&D tests.

### *Building information modelling*

According to the head of the BIM and digital services of the case company C, BIM is a data management system from the design, construction and to the operation phase. BIM is not just about the 3D model. They see that, it is the data within the model that is very important and can be utilised in many ways. Further, all their projects are designed by BIM and especially in their own development projects, they have very high criteria of the

model to utilise the model in design, and to estimate procurement and production phases. They have very precious and dedicated procedure to use BIM in their company.

Further, 2D, 3D and 4D BIM models are mostly applied in the case company. According to them, the full utilisation of 4D and 5D does not exist anywhere yet and it takes some time if they really want that the cost structure, time management and all the parameters can change, when they change the model. Such type of a system is not available in the world yet. Perhaps when the data content is precisely accurate and perfect, then the 4D and 5D can be utilised. As company C is using 4D and 5D BIM for showing time scheduling, building location and cost of the model when they have the content of the data precisely accurate.

Moreover, case company C is also facing some challenges in their current BIM model. As their design engineers still require some skills in order to do create the BIM design correctly because designers are still in the learning phase of using BIM design. Also, designers do not check their model and architecture controls while making their designs. They think that designers have to take their responsibility for what they have to deliver. It can be considered as a mind-set challenge towards digitalisation, according to the company. Further, they believe that they constantly need to improve the detailed level of skills in the construction projects and sites, so that they create their BIM model with high accuracy.

#### Data management

Company C has several data management systems and they are not integrated with each other. However, they have 6 to 7 relevant systems which are used to handle their data management system. These systems also cover the whole life cycle of the projects. In the perfect world, it could be said that it is beneficial if it would be integrated into one system but in reality, it is really challenging. According to their company, they have 40 production software and the data architecture is not Integrate-able.

### Supporting technology

According to the case company C, the digital twin is still in its emerging stage and they do not use precise digital twin models yet. As they require some integration methods to adopt it and also their clients are not demanding it as well, but according to the current market demand, few of their projects utilise some applications of the digital twin in the operational phases. However, they do not have mainstream solutions to the digital version of the product which they are delivering. They believe that it is a strategical model, and that is what they have to build. Further, they are also utilising some applications of the digital twin in the IoT devices to visualize indoor air quality, linking product information to the model and also carbon relation to the model. These are three areas of the digital twin which they are currently working on.

Further, the case company is also using VR technology to validate their construction projects, like they are demonstrating the constructing plan to their clients in order to fulfil their requirements. Further, the company has tested AR at some point on the construction sites, but both AR/VR devices are so fragile that they have not utilised them at the sites yet. However, they are applying VR applications quite a lot in their design stage and also, in some phase for their marketing purposes as well.

Moreover, company C believes that it is important to find the real value to utilise digital twin, AR/VR technologies in their current operations. They have to think about the functionality point of view not just from the technology point of view. Thus, they think that they still require some time to find the potential benefits to utilise these technologies, which, is the current big challenge faced by them.

Further, the case company is using IoT technology for various purposes. They are using IoT in the concrete activities where they can follow the data of the measurements. Also, they have installed several IoT devices in their construction buildings depending upon the contract to collect real-time data. Further, in their headquarter, they have around 4000 IoT points which are used to visualise the data according to the digital twin perspective. Also, the 5G network is still not fully utilised yet and but they think it will allow them to have better connectivity on the sites. Further, they believe that towards the adoption of the digitalisation, machine learning is also essential in terms of knowing the prices,

market situations, analysing product development, and investment opportunity. They think that there is a need to define the use of technology in their business in order to adopt the technology in an advanced way.

Also, they believe that data management is also a big challenge in the construction industry. They have a lot of data from the design and to the construction phase and a lot of data standards which are the obstacles of use these technologies. They further mentioned that there should be a common data standard available which would allow following the data from the beginning to end. Also, there should be serial numbers for the construction products like the GTIN (Global Trade Item Number), so that they could track the product and get reliable data from it.

### **3.5 Current practices in case company D**

#### *Robotization in the construction:*

Case Company D believes that robotization has the potential to provide economic advantages to their company. They think that using more robots within factories will be important for them as they are facing challenges to get skilled personnel for their factory work. Company D has a plan to utilise robots in production activities in the near future, as they are willing to make their production lines smarter. They believe that there is a lot of manual and tedious work which can be done by robots and they can deploy human workers to the other economical tasks. Moreover, the company uses digital cranes, jumbo drills and other digital machines in their construction activities. On the other hand, company D is not mainly using robots in their construction prefabricated activities, as they require advanced modular structure for their products and they have a plan to acquire it in the near future. However, they believe that implementation of robotization has some difficulties, like initial investment and maintenance cost, robotics software and its applications. But they feel that irrespective of these challenges there is still an economical benefit to investment on the implementation of the robotization. These days they are looking for suitable robotics systems which can be utilised in admirations, procurement, and other processes.



### Building information modelling

Case company D has a BIM model, which is accurate enough and well enable to fully utilise and automatize in the production of the log parts for the houses. However, it is not accurate enough for some smaller sub-parts of the houses like, outside panels, structures underfloor and some other sub-areas of the houses which are sub-contracted. They have BIM models for architecture, designer, HVAC, etc. They are getting BIM model in industry foundation classes (IFC) format and then they integrate BIM models with their CAD tools, and optimise in different ways. Currently, they are mainly using 2D and 3D BIM models for their construction projects. However, they believe that in the standard maturity level of BIM, their company's is between level 1 and level 2.

They think the current challenges in their BIM is that they do not have the common BIM library in which all the models are available. Everyone like Architecture designer, planner, etc. has their own model, which creates difficulties in terms of integrating their models. If they have a common library, then all could have access to everyone's model and based on that they could create standard and efficient models. Also, in the wood industry, there is no kind of standard BIM models and structure available. Every collaborating company have their own structure and models which create difficulties when attempting to integrate and get the correct data for their BIM. The challenges can be solved if the company has a centralised data management system and standard structure and design for their products.

### Data management

Currently, company D is utilising sub-data management systems to have access on their data, but do not have a centralised data management system which creates various challenges in terms of access to the master data of their products in real-time, and it also limits the full utilisation of the BIM model. Thus, they have launched a project in their company in which they are testing the suitable product data management (PDM)/ product life management (PLM) software. They believe that in the future there will be a centralised data management system in their company, where all the data related to the products, construction process, sales, customers related data are at the same place, like which can be seen in Figure 5 in the literature review section.

Supporting enabling technology.

Case Company D believe that according to the current demand and market situation it is important to have the efficient enabling technologies to have a competitive advantage. Further, they think that digital twin is highly beneficial these days in the construction industry and they have seen various potential applications of a digital twin, which have already been utilised by some companies in Finland and have received great results from it. However, they believe that according to their current situation digital twin is not so important for them but they think that when they move more towards in the digitalisation phase, they will probably utilise these kinds of technologies. However, they believe that they still require some five years to implement a digital twin in their company.

Moreover, it is interesting to know that case company D is not utilising AR/VR applications these days. However, they were using VR applications quite a lot in their marketing and sales point of view, but they are not using it anymore. They think there is a lot of suitable animation software are available, which can be used that are quite flexible and efficient compared to VR. They believe that possible reason behind this is that it is hard to update the VR software and application all the time. But according to their opinion, they believe that earlier the VR applications were not efficient but due to the advancement in the technologies, they have become smarter these days and more efficient to be utilised by the companies. On the other hand, they believe that supporting enabling technologies have the potential to manage the life of cycle of their construction building. Like the integration of BIM and a digital twin with the supporting technologies could assist in the maintenance tasks. But it will be quite challenging according to them, as well integrating these technologies. However, currently, they are looking for some solutions with the help of supporting technologies to store the sales data in a digital platform so that the company can get access to the requirements of their customer data in real-time, and reduce the manual work to input the data. Thus, they believe that supporting technologies will be helpful if they have accurate models and structure for construction products with the centralised data management system.

### 3.6 Current state analysis synthesis

In terms of *Robotization*, all the four case companies have different challenges, including lack of data, the requirement of a standardised modular product for the robot to operate, fear of employees losing jobs, etc. However, even though the challenges vary, few things are common, including robotization implementation are initial investment cost, robotics software and thinking approach towards robotization. Also, in the pre-fabrication process robotization is not mainly used in most of the case companies, however company C collaborates in robotization in the pre-fabrication process with their sub-contractors. They are applying the BOKLOK module system and is considered to be partially using robotization in pre-fabrication. All the case companies believe that the use of robotics in the future is inevitable which would be beneficial to fulfil future demand.

In terms of digitalisation there are various digitalization concepts that are yet to reach the mature stage. One of the important digitalisation concepts that plays an important role in the construction industry is BIM. BIM utilised in most of the case companies on a basic level, and currently it is challenging to complete the entire construction process without BIM. However, the maturity level of BIM in all the case companies is between level 1 to level 2, in most cases its inclined majority is towards level 2. However, case company C believes that they are on the verge of reaching maturity level 3 in the future and considers having a few aspects of level 3 BIM in the company. The standard maturity model can be seen in Figure 8 in the literature review section. One common challenge found in all the case companies is that BIM was not found to be centralised to all the sub-processes of construction, since it is difficult to integrate BIM in few areas of the process like Architecture, and HVAC design models etc. Also, data management to support BIM is not completely centralised in case companies, but data management is followed separately in the sub-processes of construction, which makes the implementation of BIM a challenging task for most of the empirically analysed case companies. Company A, however, uses a centralised data management system and considers it to be a huge impact in terms of information flow and flexibility from the construction process point of view. Despite that, they are facing challenges in utilising the data properly. Most of the companies have not implemented IoT principles in their construction process. However,

most of the companies believe that continuous improvement in BIM can be an important basic aspect in the future of their businesses in terms of digitalization.

In terms of supporting enabling technologies, digital twin is considered as one of the most important following with AR/VR. However, all the case companies are not using high-level maturity digital twin. They are still in the beginning stages of digital twin and one of the main reasons being the lack of BIM maturity in the organisation. Further, AR/VR are not mainly utilised in the construction process as data management lacks in most of the case companies. Also, company C believes that AR/VR devices are so fragile that it is hard to use them in the construction process. However, case company C uses VR mainly in the designing phase and company B uses it for marketing purposes for better sales at the moment and they have plans to take the next leap towards AR in the future. Similarly, other enabling technologies like 5G, IoT, and cloud computing etc are least utilised in the construction process as they are very dependent on the major enabling technologies and digitalisation processes like digital twin, AR/VR and BIM. Most of the companies believe that these technologies do not happen overnight and it is a long process to be achieved. Further, the key finding from the empirical research is synthesised in Table 7.

Table 7: Key points from the empirical research

| Company | Robotization   | BIM  | Data Management   | Supporting technologies  |
|---------|--|--|---|--|
| A       | *Robotization is not highly used in the company. Only in construction sites.   | *BIM is a lifeline for the company and is helpful in alliance projects                                     | * Centralised data management system exists                                       | *Integration of technologies is a tedious task at the moment   |
|         | *Beneficial in the future for Company A  | *Continuous updating required for better utilisation in the future   | * However, there are problems in terms of data use                                | *Requirement of better cloud system as the first necessity   |
| B       | *Robotization is not used widely. After 5 years they plan to implement sophisticated robotization, in case they have a clear modular product structure | *BIM is utilised up to a basic level   | *Centralised data management implemented recently                                 | * Supporting technologies utilised only with contractors   |
|         |  | *However, Integration of high-level BIM technology is a difficult task at the moment                       | *High requirement of centralised data required for improvement of the data system | * Currently not required for the current product offering  |
| C       | *Robotization is used in a limited application, however, sub-contractors utilised robotization for pre-fabricated activities                           | * High-level BIM utilised. According to the company, they have satisfied BIM level,                        | *No centralised data system available   | *Supporting technologies is utilised in end phase construction building activities like IoT applications |
|         | *We do not have current market knowledge on how valuable robotization will be for our company.   | *Integration of BIM models with other sub-models like CAD etc would be beneficial according to the company | * They find centralised data is helpful in the future, but difficult to implement | *However, there is the need for other enabling technologies to support the current enabling technologies |
| D       | *Sophisticated Robotization is not utilised widely in company D  | *BIM is utilised in the production of log parts, but face difficulties to integrated sub-parts of house    | * No centralised data management exist  | * Utilising enabling technologies at some point and it is because of lack of data management             |
|         | *Robotization is said to be beneficial for the company in the future and will be utilised more when the company uses modular products                  | *Company considers them not utilising BIM very well at the moment  | *Plan to implement centralise data in the future                                  |  |

## 4 RESULTS AND EVALUATION

This chapter answers research question 3 by considering aspects from the literature review and challenges or requirements identified in the empirical research. This chapter juices out the key elements required to have better construction performance in terms of digitalisation and robotization. The following figure 13 in chapter 4.2 shows the framework that may provide the basis on how large-scale construction companies can take the next leap towards robotization and digitalisation. Prior to the framework chapter 4.1 justifies the reasons for creating such a needful framework for large scale construction companies.

### 4.1 Motivation towards the framework

The motivation towards building a base framework for case companies comes from the challenges that were retrieved from the empirical research and literature review. The literature review showed us on how few challenges can be overcome, and at the same time also showed how the empirical research did not validate few of the findings from the literature review. This chapter discusses on providing reasonability on why having a basis on robotization and digitalisation is important for companies in terms of implementing robotization and digitalisation technologies. According to the report of the Industrial digitisation review, overall, 98% of the infrastructure projects are over budget or delayed, because of the lagging productivity of the construction activities (Thompson *et al.* 2017).

#### Robotization

One aspect that can be confidently taken into consideration from the theoretical and empirical research is that robotic technology has a significant potential to provide sustainable benefits to the construction industry when considered from time and flexibility point of view. On the other hand, innovation and implementation of sophisticated robotization in the construction domain is significantly less compared to other industries. The challenges mentioned by the literature review deviate in some terms from the challenges found when conducting the empirical research. However, similar

challenges were also found, including high initial and maintenance cost, lack of expertise, and work culture factors. The most common challenges found from the literature review in terms of robotization were portability of the machine, contractor side economic factors, robotics applications, software availability and safety of humans while interacting with robotic machines. The empirical research sheds light into different challenges when compared to the literature review like lack of modular structure and product design, lack of awareness and training for workers, advance prefabrication methods and precise data management requirement.

### Digitalisation

It is believed that digitisation is the lifeline to get high economic benefits and improve, the quality of the construction infrastructure and building processes. Due to the lack of innovation and lower adoption of technology, the overall construction's productivity is reduced. Currently, case companies have access to the available technological platforms to some extent, but due to the lack of expertise and knowledge, they are unable to use it in an optimised way. From the empirical research, it is observed that the companies have different views towards the adoption of technology like case company B has a different view about the digital twin as compared to other case companies. Also, digitalisation, BIM, digital twin and support technologies like AR/VR, IoT and cloud computing, play an important role in the construction industry and is observed to have faced a lot of challenges.

From the literature point of review, the top challenges towards the adoption of digitalisation that were highlighted includes, security and data privacy issues, awareness of technology, lack of technological readiness level, lack of training and knowledge, lack of data interoperability in BIM. These challenges were pretty similar for the enabling technologies. However, digital twin also had similar challenges, but other unique challenges like Large database requirements, few uncertainties in the quantification of simulation results, and lack of quality information across the organisation.

However, from the empirical point of view, it was found that the topmost challenges in digitalization mostly inclined towards BIM like the integration of existing models, limitation within existing technology, centralised data management system. Overall the

most common challenges found in both empirical and literature review towards the embracement of the technology were the absence of standard or universal infrastructure, lack of expertise and the integration of technologies.

### Prefabrication

As observed from the research, the construction industry has had a bad image in terms of the ecological point of view. It is considered as labour intensive, tedious and least ecological industry, especially in terms of dirty, dusty and sound pollution. However, from the literature and empirical research, it was found that prefabrication or modular building construction method is a great approach to make the industry more efficient, greener and safer. According to the literature review, prefabrication method is efficient technique, but it has several challenges involved in it, like inflexibility in the change of design, space requirements for pre-fabricated large components, and time and cost required for initial implementation. However, the case companies are also applying prefabrication methods at some point, but still, they require some advancement in it. As they are facing some challenges like, standardising the product design and product structure, productising the material, technical engineering issues and product data management problems. These challenges bring the need for embedding prefabrication in the construction process as in the future it can indeed improve construction process performance.

## **4.2 Suggested framework**

The framework suggests that pre-conditions should be applied to enhance the robotization and digitisation practices in-order to improve the performance of the construction activities. This framework can be seen in Figure 12, mainly focusses on elements that found as a potential need for companies to implement. Thus, it is essential to apply the following pre-conditions to evolve construction performance. From the above framework, market analysis and data management are the two key elements. Further, this framework is supported by the sub-elements that need to be considered like continued training, modular and prefabricated design creation, and maturity analysis. If the objectives of this framework are synthesised, it can be as follow:



- Create awareness and train people
- Create a new market for construction products and analyse the current market status
- Make standard product structure and product design
- Improve the flow of data
- Integration of technical tools into the construction production system

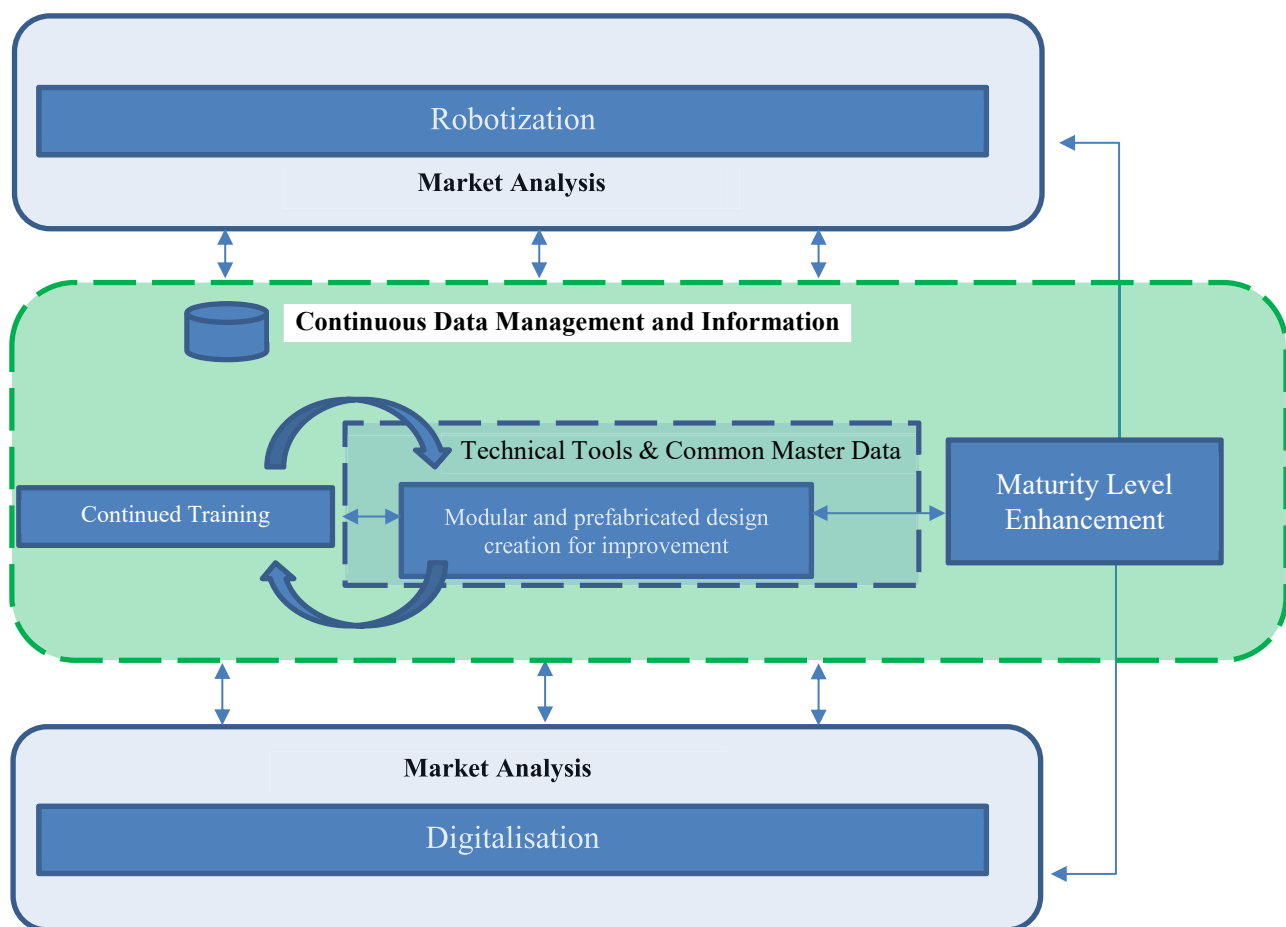


Figure 12: Framework to provide a basis in order to implement robotization and digitalisation

### Market analysis

According to this research, one can believe that construction industrial players do not view the significance of digitisation and robotization in all areas. Through the adoption of digitalization and robotization practices, they can conduct market analysis in which

they can get potential data from logistics, procurement, production construction, sales and marketing and after-sales phases. At the same time, it is also important to gain market data in terms of their competitors, market size they are dealing with and other market analysis aspects also from the robotization and digitalisation perspectives.

It is believed that it is very important for companies to understand their challenges better and also the impact on their business. However, this can be challenging for some companies because of the various factors involved. This could be solved by explicit market research on how companies can improve their construction process performance. It is believed that the first step to enhance digitalization and robotization is to begin with a construction feedback loop market analysis, as shown in Figure 12.

### Data management

Data utilisation in construction can help when it is involved and integrated early in the construction process. It is very important to model the product data structure for the project in collaboration with the required stakeholders and key actors of the organisation. Data management connected to different construction processes as can be seen in Figure 13. The important aspects from the market analysis with the integration of data management in the construction process activities can improve communication in the organisation and especially in terms of training as well. It also enables to integrate and exchange the data in different processes so that accurate and real-time can be accessed. However, this brings the importance of data governance and data ownership, which is an important point to be developed in this framework. This early involvement of a robotization and digitalization culture with the support of data management will tick in the pre-requisites for the company to take the next leap for BIM, Digital twin and other enabling technologies. A good example on how data management is connected to different constructions processes is shown in the figure below. With a well-structured centralised data, a lot of construction processes can become proactive. Also, as per previous research and also as per the challenges seen in the empirical research, it can be confidently said that a well-structured data management can hold on being a basis to confidently implement modern technologies. Most of the technologies being data-driven these days make it inevitable to emphasize data management in the construction process. Also, for construction processes to maintain the product throughout the product life cycle,

data management is highly recommended. Further information about data management can be seen in section 2.4.

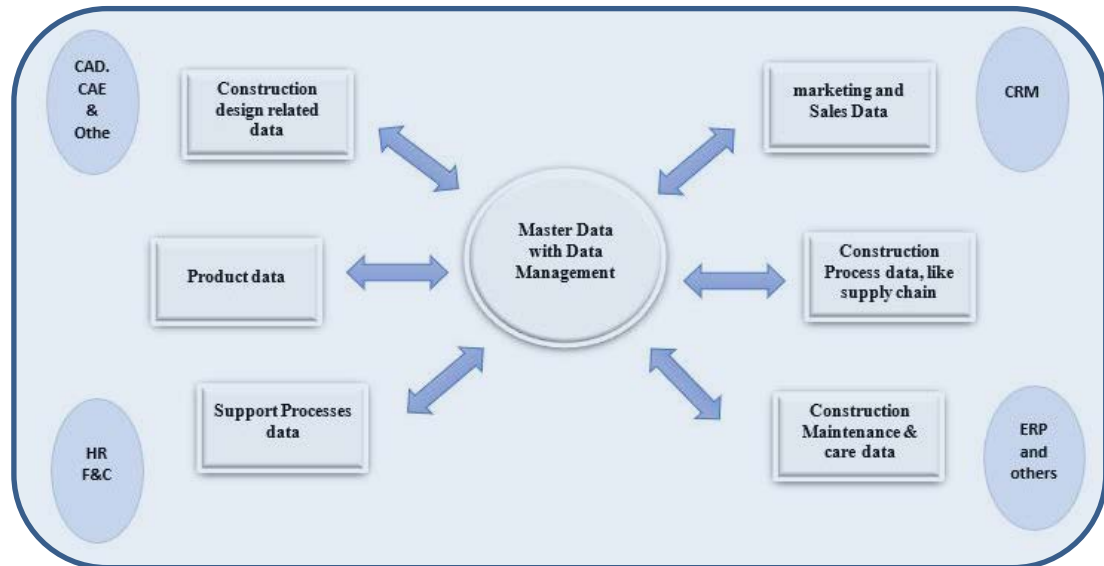


Figure 13: Data management connected to different construction processes

### Continued training

According to the European Commission, the construction industry is lacking behind in providing specialised training (European Commission). However, in that case, continued training will be helpful and make the sector more attractive, especially for blue-collar workers. From the framework, when the results from the market analysis provide the continuous information of the critical data, then companies will be aware on which construction products and services are demandable among their customers, or they can be familiar with which construction processes should need improvement, in order to be efficient and productive in terms of cost, quality and reliability. Thus, to achieve those goals, it is essential that workers should be skilled and trained enough so that they would be constructive during their construction activities. This also, in a way can solve problem on the fear of workers losing their jobs. Further, within the company employees, managers, etc., have a different viewpoint about their own products. Hence, in that case, the continues training sections provided by the company to their employees will be highly important to bring everyone on the same page.

Also, during the literature and empirical phase, it is observed that there is a lack of professional workers who are familiar with digital technologies. Digital skills and education aspects is a potential area that enables to change the traditional methods of the construction industry. As the current mindset of the construction workers must be changed through professional education and training. Digital learning platforms and professional courses would be highly beneficial for the construction workers. Further, it can believe that human resource management, in collaboration with various stakeholders of the company, will play an important role provide continuous training to their workers.

#### *Modular and prefabricated design creation*

With simultaneous training and development, modular and prefabricated design creation is highly essential for the construction industry and according to the current market situation as the construction industry is not as efficient and productive in comparison to other industries. In that case, if the construction industry utilises proper modular structure for their products, then they may able to utilise their resources in an efficient way. From the empirical research, it was observed that case companies are applying modular and prefabricated design for their products, but still they needed some improvement in order to reduce costs and make high-quality products. It can be observed that due to the lack of product data management and engineering technical issues within the case companies, they are unable to make the standardised modular and prefabricated design of their product. Thus, the framework emphasises that the proper flow of data and centralised data management system should be needed to create the standardised product structure, which can be seen in Figure 14. Also, proper training and knowledge of technical skills will indirectly reduce engineering issues that create hurdles to make the modular structure.

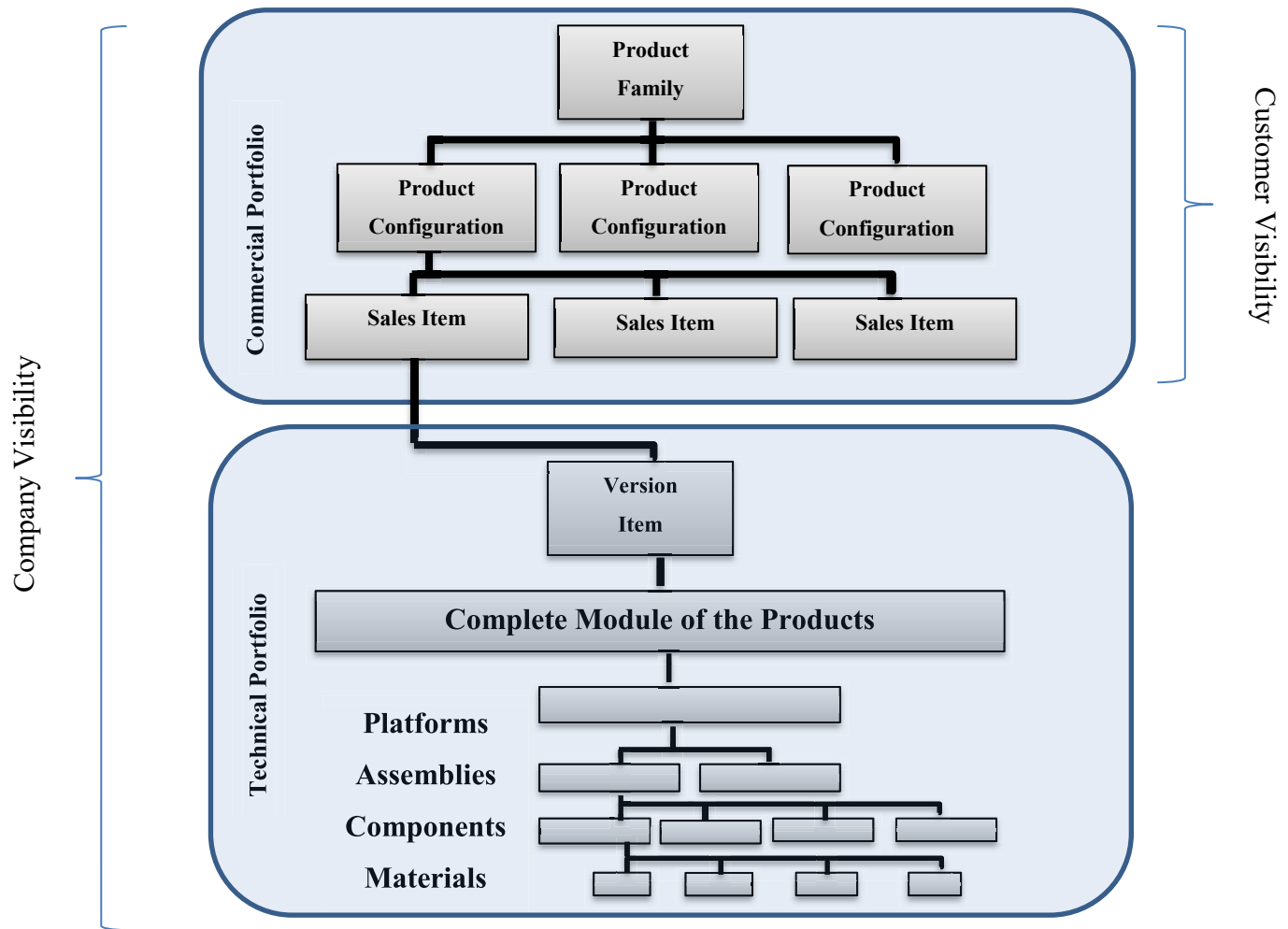


Figure 14: Modular product structure (modified from Tolonen *et al.* 2014)

However, to achieve a clear modular product structure it is very important for companies to define their product structure. The modular product structure is defined in two main parts, commercial portfolio and technical portfolio. The commercial portfolio is mainly focusing on the customer visibility point of view for the potential customer of the company and public audience. The commercial portfolio includes all the attributes which generate sales for the company. It includes product family, product configuration and sales items of the company. Further, the commercial portfolio plays an important role to bring uniform product sales information between the different parts of the company. For example, all the sales personnel have clear information about the product and its sales items which give clear information to their customers and reduce conflicts.

However, the other part of the modular product structure is the technical portfolio, which is primarily for the companies. It contains all the different levels of the information regarding version items and the platforms, assemblies, companies and materials required for the modular products. Further, in this section, different team players within the company like, product development, purchasing, production and logistics teams are working to finalise and modify various product levels. Companies will have a clear view of the overall cost of their production. Thus, it clarifies how the standardised product structure enables to store all the essential information and knowledge regarding products in an understandable manner, which would be highly beneficial for all the business processes. Further, it also allows companies to use their available resources in an efficient way and permits to fulfil the strategic goals throughout the product life-cycle.

All of these explicit product structures will definitely play an important role when the company is dealing with large data of pre-fabricated parts for various market segments. It will impact business processes when companies shift their construction business process towards complete pre-fabrication in the future. Also, there will be a lot of new and existing pre-fabricated models entering and exiting the portfolio for which the above-mentioned data management and modular product structure will play a vital role.

### Maturity analysis

The characteristics of the maturity analysis consist of five levels; initial, managed, defined, quantitative and optimised. It is essential for companies to understand the maturity characteristics, so that they can find out at which maturity level they are at. If they conduct maturity analysis in a precise way, it will help to upgrade their level. However, it was clearly observed that companies are not aware of the maturity level they are currently due to the lack of awareness on maturity models and also regarding the current market scenario, and the challenges they are facing in digitalization and robotization.

Sections 2.5.1 and 2.5.2 have described the maturity level analysis for building information modelling (BIM) and digital twin (DT). It is important that companies define the maturity level technologies based on these standardized maturity level models. From the empirical research, it was found that case companies are not able to mention the

correct level of their BIM maturity. The reason behind is this is that they have not conducted an explicit maturity level analysis to define their current BIM tools, processes, and data. Similarly, for the digital twin as digital twin is still in the emerging phase and still it not being utilised effectively in the case companies. Also, from the continuous flow of data management and information and the skilled training, better maturity level enhancement can be created, which be shown in the presented framework.

## 5 CONCLUSIONS

The industry 4.0 concept was introduced in the recent years, which have proposed the importance of enabling technologies in the industrial sectors. The advancement of robotization and digitalisation will bring numerous benefits which can help construction industry to the next leap. Further from the research, it mentioned that construction industry is the only sector which not much familiar with R&D activities as compare to the other sectors. One of the reasons is that construction industry has complicated framework which creates problem to implement latest technologies. Also, the lower investment, low profit margin and the mindset of the workers enables towards the late adopter of the technology.

Further, in this chapter, the contribution in relation to the each of the research questions are answered. The first research question (RQ1) is answered through a literature review study. The literature emphasises the importance of robotization and digitalisation in the construction industry by highlighting recent technological trends. Table 4 and 5 show the challenges and benefits of digitalisation and robotization in the context of construction industry. Furthermore, in terms of digitalization, the latest technologies like BIM, digital twin, and AR/VR are required for the success of Industry 4.0 vision in the construction are studied with their required roadmap steps. Further, integration of these technologies is also explained with the support of enabling technologies (5G, cloud computing etc.). Also, in terms of robotization, potential robots (like collaborative and wearable robots) currently used in the construction industry are discussed in this thesis. Further, the required enabling technologies have been explained. Finally, the importance of data management is explored to understand on how data management can play an important role when it comes to supporting construction processes. Therefore, the answer to RQ1 is given by thorough study of relevant state-of-the-art.

The second research question (RQ2) is answered by the empirical study. RQ2 is answered by preparing a questionnaire (refer to appendix 1 and appendix 2) by pointing out the importance of robotization and digitalisation to case companies and with the aim to understand their current state practices on robotization and digitalisation in their respective construction process. In addition to this, the highlighted challenges are also



addressed which the companies face in terms of implementing robotization and digitalisation. From the empirical research, it was clear that due to these challenges, there is a lack of framework on how to implement robotization and digitalisation in the case companies.

The research findings from both the literature review and empirical study further directs in the answering the RQ3. Based on these findings, this thesis is inclined on providing a framework that can help construction companies implement digitalisation and robotization technologies. This framework shows the need for companies to acknowledge the importance of market analysis to define robotization and digitalisation for the company, data management to manage information flow and structure throughout the construction process, requirement of continuous training to ensure the organisation is pro-actively prepared towards the implementation of digitalisation and robotization, need of modular and prefabricated design creation for improved benefits during the construction process and finally for companies to understand their own maturity level better in order to improve in the future in terms of digitalisation and robotization.

If the construction industry implements the advance robotics and digital technologies, then it has a significant chance to improve the overall performance of the construction activities. Thus, the theoretical study is conducted to find the potential benefits and barriers in order to adopt latest technologies. From both the theoretical and empirical research, it can be observed that the BIM and digital twin is promising digitalisation technology and playing a crucial role in the construction perspective. However, it is still in the emerging stage in most of the case companies, which should be developed to have the full use of the technology.

## **5.1 Theoretical implications**

As mentioned above this thesis highlights the importance and roles of digitalisation and robotization in the construction process. The theoretical implication in relation to the research questions of this thesis is explained in this chapter. The results of this thesis contribute the challenges faced by companies from a different perspective to the challenges found in the previous literature on digitalisation and robotization. Robotization

processes and the latest robots used in the construction process in case companies were studied and compared with the literature. It was found that companies have their own reasoning on not utilizing these latest robotic technologies and this is an addition that needs to be validated with the current trends (Market research future 2019, IFR 2019) of robotization in the construction industry. In terms of integrating digitalisation technologies like digital twin, BIM, AR/VR (Co builder 2018 & Lang 2019), and the other enabling technologies to the construction process like 5G, cloud computing, IoT etc., this thesis provides a basic pre-requisite and fills the gap on how to approach towards integration. Also, in terms of maturity level, the framework presented in this thesis shows the importance on how maturity analysis example BIM (GCCG 2011) can be approached using the key elements of market analysis, data management, and other sub-elements mentioned in the framework section related to the construction process.

Further this thesis supports the current literature available in data management in the construction industry (Harkonen *et al.* 2019, Silvola *et al.* 2011) and brings an addition on how data management can play an important role for the current challenges faced by companies. Further also validates the fact that data management should be considered when digitalising and robotizing companies. Other than identifying new challenges this thesis validates various challenges and benefits mentioned in the past literature regarding robotization and digitalisation from the empirical research point of view.

## 5.2 Managerial implications

The research study suggests a framework to improve digitalisation and robotization practices in the construction industry. The created framework would provide the base information that will help managers to enhance their decision-making power in-order to adopt/enhance I4.0 technologies in both large-scale companies and SME's. As it can be seen that companies are facing challenges to adopt the latest available technologies, hence proactive measures through this framework will help managers to improve construction performance. Further through the framework, companies can fulfil several objectives, like, create awareness and train people, create a new market for construction products and analyse current market status, make standard product structure and product design, improve the flow of data and integration of technical tools into the construction

production system. Moreover, in reality regardless on how the design of the product (building, infrastructure, house) is made, there is always deviation in the final construction process. The reason could be that site managers do not have access on the real time data which allows to build the design in a different way. Hence, the centralised digitalisation technologies allow to solve this critical issue. Technologies enables to provide precise and reliable data in real time which would help them to accurate building designed as it was modelled.

### **5.3 Reliability and validity**

Lincoln & Guba (1985) suggests analysis through credibility, transferability and dependability and confirmability. In terms of credibility, case studies helped in understanding real world problems. Semi-structured interviews and survey questionnaires helped in clarifying the research better with explicit and understandable insights. The companies were selected in a way to support the findings from the literature and empirical research and the required personnel were interviewed respectively which was the top management in our case. The study is comprised of three different parts and all the parts are linked with each other, which helps to get the reliable outcome of the research. Interviews were conducted face to face which helped getting better insights. In terms of transferability, most of the companies were large scale companies, and all the companies were not operating globally. Companies did support digitalisation and robotization practices and also implemented them to some extent. However, with the involvement of different topics or maybe a focussed topic, would have helped bring more insights towards this research. In terms of dependability, a consistent questionnaire was utilized to align the findings of this research. This allowed gain fruitful insights to understand the research in dept. However, a greater number of case companies would help get better insights in this research. Finally, in terms of confirmability there was some level of incomplete information received from the empirical research for instance in terms of the definition of digitalisation and robotization for the company. However, this was considered in a positive way in the results of the thesis, but on the other hand it would have been helpful if the companies understood digitalisation and robotization to a better extent for better results.

## **5.4 Future research**

The need for improvement of the current framework and validation of the proposed framework will be required. Further, this technology can be implemented in another sector as well like healthcare, agriculture, Manufacturing etc. Another important future proposal for this project is to focus on a mixture of SME's and Large-scale enterprises, because SME's may also face similar problems as large-scale companies in terms of gaining a basis towards digitalisation and robotization. Moreover, there is also need to improve the framework in terms of data governance and data ownership and future research can focus on building this framework in terms of these key research components (data governance and data ownership).

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## APPENDICES

### Appendix A: Questionnaire model for case companies

| Question Number                       | Theme and Questionnaires   |
|---------------------------------------|--|
| <b>Background information</b>         |  |
| Q1                                    | What is your title and role in the organisation?   |
| Q2                                    | How many employees are currently in your organisation?   |
| <b>Robotization in construction</b>   |  |
| Q3                                    | Does your company utilise robots and could you explain more in detail how you are using those on your processes?   |
| Q4                                    | What are the equipment/machines utilised in the assembly process during construction by your company, currently?   |
| Q5                                    | In addition to Q3, does your company utilise modular structured or Pre-fabricated parts for assembly?  |
| Q6                                    | Does your organisation believe in having more advanced robots in the construction processes?   |
| Q7                                    | Have you been thinking that utilisation of robotization will enhance productivity and/or make ergonomic better and/or reduce stress on human-worker?   |
| Q8                                    | What do you think are the challenges in the investment of advanced robots in the assembly process? Is it worth it 5 years down the line even tough with high initial investment costs?                               |
| Q8.1                                  | What are the main challenges in robotization in construction assembly in your opinion?   |
| Q8.2                                  | How would you solve these challenges?  |
| <b>Building information modelling</b> |  |
| Q9                                    | Are you aware of the digital design knowledge, e.g. BIM (Building Information Model)? If yes could you explain how BIM is applied in your company or how you believe it should be applied to provide the most value? |
| Q10                                   | What are the different types of planning methods utilised by your organisation during construction? Like 2D drawings, 3D models, 3D BIM, 4D BIM  |
| Q11                                   | Do you use data management systems in your company? Which ones?  |
| Q11.1                                 | Do these systems cover the entire life-cycle of construction?  |

|   |   |
|---|---|
| Q11.2   | Can these systems support the life-cycle management of the constructed buildings?   |
| Q12   | What are the challenges in the implementation of BIM in your opinion?   |
| Q13   | Do you think BIM will be beneficial or compulsory for your company in the future?   |
| Q13.1   | What are the challenges of BIM in your company context?   |
| Q13.2   | How would you solve these challenges?   |
| <b>Digital twin and AR/VR</b>                           |   |
| Q14   | How do you understand the concept of Digital twin and AR/VR (Augmented Reality / Virtual Reality)   |
| Q15   | Does your company implement Digital Twin or AR/VR in any part of the construction process? How?   |
| Q16   | Does your company use very detailed digital/virtual models as replicas of the physical model that is going to be built?                                     |
| Q17   | Do you think the integration of AR/VR with Digital twin with the support of BIM will help in the improvement of construction process performance? (Picture) |
| Q17.1   | What are the current challenges of using Digital twin & AR/VR in your context?  |
| Q17.2   | How would you solve these challenges?   |
| <b>Supporting Enabling Technologies of Industry 4.0</b> |   |
| <b>IoT, 5G, Cloud computing</b>                         |   |
| Q18   | Does your organization use or plan to use IoT or 5G or cloud computing?   |
| Q18.1   | What are the current challenges of using IoT, 5G, cloud computing, in your context  |
| Q18.2   | How would you solve these challenges?   |
| <b>Suggestions</b>                                      |   |
| Q19   | Is there anything you would like to add to the previous themes and topics that I have not asked?  |
| Q20   | Could you give me some suggestions on my current research?  |

## Appendix B: Short survey questionnaire model for case companies

- ❖ **In which of the following phases in the construction process do you think “Digitalisation” will be most utilised? Or is currently most utilised in your organisation**

|  |         |
|--|---------|
| Designing and Pre-construction         | _____ % |
| Procurement phase                      | _____ % |
| Actual construction and building phase | _____ % |
| Post-construction (Service phase)      | _____ % |

- ❖ **Do you believe that for enhanced construction process - Early adopters of emerging digital technologies will be ahead of the game?**

|       |                          |
|-------|--------------------------|
| Yes   | <input type="checkbox"/> |
| No    | <input type="checkbox"/> |
| Maybe | <input type="checkbox"/> |

- ❖ **As per your experience and understanding, do you think there is a requirement of advanced technological collaborative robots during the construction assembly process?**

|       |                          |
|-------|--------------------------|
| Yes   | <input type="checkbox"/> |
| No    | <input type="checkbox"/> |
| Maybe | <input type="checkbox"/> |

- ❖ **Kindly tick top challenges from the options below in the implementation of advanced collaborative robots during the construction assembly process?**

|  |                          |
|--|--------------------------|
| High initial and implementation cost       | <input type="checkbox"/> |
| Limited resource availability              | <input type="checkbox"/> |
| Maturity level of the technology           | <input type="checkbox"/> |
| Lack of awareness and training for workers | <input type="checkbox"/> |
| Modular product design                     | <input type="checkbox"/> |
| Prefabrication                             | <input type="checkbox"/> |

- ❖ What are the top pre-requisites required to support BIM as technology as per your understanding?

Better integrated software system \_\_\_\_\_  
 Better Data Management \_\_\_\_\_  
 Supporting Digital Twin technologies \_\_\_\_\_  
 AR/VR \_\_\_\_\_  
 6G Sixth Generation network \_\_\_\_\_  
 Cloud computing \_\_\_\_\_  
 All of the above \_\_\_\_\_

If other, please mention - \_\_\_\_\_

- ❖ How do you think the future trend of the Robotization and Digitalization in the construction industry will 10 to 15 years down the line?

| 1             | 2                  | 3     | 4        | 5     | 6                | 7                   |
|---------------|--------------------|-------|----------|-------|------------------|---------------------|
| Insignificant | Little Significant | Minor | Moderate | Major | Very Significant | Totally Significant |

| Level of Agreement                                     | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|--|---|---|---|---|---|---|---|
| Greater awareness about the technologies               |   |   |   |   |   |   |   |
| Technological application easy to operate and maintain |   |   |   |   |   |   |   |
| Greater standardisation would be available             |   |   |   |   |   |   |   |
| Technology would be fully ready                        |   |   |   |   |   |   |   |
| Lack of digital products as one digital model          |   |   |   |   |   |   |   |



- ❖ Do you believe the approach of digital design, Prefabricated parts, and better on-site assembly can reduce the entire time schedule of a construction project?

|        |                          |
|--------|--------------------------|
| If Yes | _____ %                  |
| No     | <input type="checkbox"/> |
| Maybe  | <input type="checkbox"/> |

- ❖ Do you think the utilisation of an Integrated BIM + Digital twin system with AR technology help improve your entire Business model?

|            |                          |
|------------|--------------------------|
| Never      | <input type="checkbox"/> |
| Maybe      | <input type="checkbox"/> |
| Definitely | <input type="checkbox"/> |

- ❖ Do you think Small scale companies working with only small-scale houses can utilise these technologies? In other words, is it cost beneficial for their market?

|       |                          |
|-------|--------------------------|
| Yes   | <input type="checkbox"/> |
| No    | <input type="checkbox"/> |
| Maybe | <input type="checkbox"/> |